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Real-Time Probabilistic Neural Network Performance and Optimization for Fire Detection and Nuisance Alarm Rejection: Test Series 2 Results

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| 13. ABSTRACT (Maximum 200 words) A second series of tests was conducted to evaluate and improve the multivariate data analysis methods and candidate sensor suites used for the Early Warning Fire Detection (EWFD) system under development. The EWFD system is to provide reliable warning of actual fire conditions in less time with fewer nuisance alarms than commercially available smoke detection systems. Tests were conducted from 25 April to 5 May 2000 onboard the ex-USS SHADWELL. This report documents the performance of the probabilistic neural network achieved in real-time during this test series. Further optimization of the algorithm has yielded performance gains over the real-time results. Modifications have been made that improve the real-time data acquisition and the ion sensor calibration. Background subtraction was investigated and will be used in future tests. The best performance was provided by a four sensor array consisting of ionization, photoelectric, carbon monoxide, and carbon dioxide sensors. | | | | |
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Real-Time Probabilistic Neural Network Performance and Optimization for Fire Detection and Nuisance Alarm Rejection: Test Series 2 Results

1. Introduction

The U.S. Navy program Damage Control-Automation for Reduced Manning (DC-ARM), sponsored by the Office of Naval Research, PE0603508N, is focused on enhancing automation of ship fire and damage control systems. A key element to this objective is the improvement in situational awareness by improving current fire detection systems. As in many applications, it is desirable to increase detection sensitivity, decrease the detection time and increase the reliability of the detection system through improved nuisance alarm immunity. Improved reliability is needed such that fire detection systems can provide quick, remote and automatic fire suppression capability. The use of multi-criteria based detection technology offers the most promising means to achieve both improved sensitivity to real fires and reduced susceptibility to nuisance alarm sources.¹ A multi-year effort to develop an early warning fire detection system is currently underway. The system being developed uses the output from sensors that measure different parameters of a developing fire or from analyzing multiple aspects of a given sensor output (e.g., rate of change as well as absolute value) and a neural network for fire recognition. A second series of prototype development tests were conducted on the ex-USS SHADWELL² from April 25 to May 5, 2000 to evaluate candidate prototypes of the early warning fire detection system (EWFD).

Improved fire recognition and low false alarm rates were observed using data from full-scale laboratory tests.^{3,4,5} Several different sensor combinations were identified for use with a probabilistic neural network (PNN). Full-scale, shipboard tests were conducted on the ex-USS SHADWELL to further develop detection algorithms and to expand the fire/nuisance source database.^{6,7} Using these two data sets, two candidate suites of sensors were identified for prototype development.⁷ Test Series 1 tested the real-time responses of the prototypes.^{8,9} Two months later, under different environmental conditions, the optimized prototypes were tested with more fire and nuisance sources.¹⁰ The results of Test Series 2 shipboard testing, and the subsequent optimization of the prototypes are described in this report.

The classification of fire and nuisance events and the speed of the probabilistic neural network (PNN) were used to determine the performance of the multi-criteria fire detection system in Test Series 2. The EWFD system with the PNN developed for real-time detection, demonstrated faster response times to fires compared to commercial smoke detectors while the overall classification performance was comparable to the

commercial detectors. Some problems with the real-time implementation of the algorithm using the training set that was developed following Test Series 1 were identified and have been addressed in this report. Many problems were experienced during this test series and will be discussed. Using a variety of methods for speed and classification improvements, the PNN has been extensively tested and modified accordingly. As a result of the optimization efforts, significant improvements in performance have been recognized. A detailed examination of the correlation of the ionization detectors in the training set and in the prototypes are described. This report also investigates the effects of the training set on system performance.

2. Experimental

The selection of the sensors that comprise the two prototypes that were used during Test Series 2 was completed in December 1999 and were the same as in Test Series 1. The laboratory and SHADWELL August 1999 data, which jointly comprised the PNN training set, have been described and discussed in great detail.^{3,4,5,6,7} Furthermore, the down selection of sensors from a pool of 14 possible candidates has been described in detail.⁷ The two sensor arrays chosen were: Prototype 1 - ionization (ION), photoelectric (Photo), carbon monoxide (CO), relative humidity (RH), and carbon dioxide (CO₂) and Prototype 2 - ION, Photo, CO, RH, and Temperature (Temp). The Simplex ionization and photoelectric detectors used in the laboratory and shipboard tests were not suitable for use in the prototypes because they could not be setup to provide analog values that could be processed in real-time. System Sensor ionization and photoelectric detectors were obtained as an available substitute. Optimization experiments were performed prior to Test Series 2 to determine the best parameters for the PNN and were described in detail in reference 9. These optimization experiments included testing background subtracted data, magnitude and slope calculation variations, and training set composition. The PNN code used during Test Series 2 had been modified from that used in Test Series 1 by removing a data buffer. The new training set described in reference 9 was used for only one test in real-time during Test Series 2 due to its poor performance. Therefore, all further tests with that training set were conducted by post processing and the real-time code used the old training set used in Test Series 1.

2.1 Real-Time PNN

The real-time deployment of the PNN required data acquisition, processing and transfer of data from LabVIEW to a Matlab script. The real-time Matlab code used during Test Series 2 is given in Appendix A. In addition, a flowchart of the code is shown in Figure 1. This flowchart shows how the PNN is incorporated into the real-time analysis of sensor data including pre-processing, pattern calculation and scaling. The vector of input sensor responses (X_{current}), one number for each sensor in the array, comprise the set of data that is passed to the algorithm for pre-processing and PNN analysis during real-time deployment. For prototypes 1 and 2, the vector was 5 elements long, one for each sensor in the array. Since raw sensor responses had been chosen, only the ion and photo detector outputs were processed after data acquisition. The conversion from Δ MIC output to percent obscuration/ft and then from percent obscuration/ft to

percent obscuration/m was performed for each ionization detector and from percent obscuration/ft output to percent obscuration/m was performed for each photoelectric detector. The resulting pattern (sensor vector) was added to the end of the 25x5 matrix, data_history, and the first row was deleted to maintain the size of the matrix. In this manner new patterns were added and data_history was updated and reflects the most recent (25) patterns collected. From data_history, the pattern magnitudes and slopes were computed and then autoscaled (mean zero and unit variance) using the means and standard deviations derived from the training set. The resulting scaled pattern was then submitted to the PNN algorithm for the classification and determination of the probability of a fire event. The alarm state was triggered if the probability was greater than 0.75 for three or more consecutive predictions.

2.2 Test Series 2: Experiments and Sensor Combinations

Test Series 2 is a continuation of Test Series 1 and is described in Reference 10. The names, classifications, and descriptions of the experiments performed in both tests are given in Table 1. Tests 38-88 were collected during Test Series 2. Four prototypes were used, two were prototype 1 and two were prototype 2. One of each type was positioned in two different locations. This report describes the results from Location A. Additional sensors were included in the tests at Location A, and these were oxygen (O_2), hydrogen sulfide (H_2S), nitrogen oxide (NO), hydrocarbon (HC), residential ion with cover removed (ION Chamber), and residential ion (RION). The responses of each sensor were collected and stored in a matrix. Each of these response matrices could be used to test algorithms being developed. The response matrices were usually tested in a playback mode, where each test was treated in the same manner as if it were being collected in real-time. Each row in the matrices was a point in time from the test. Data was collected every 2-8 seconds. The columns contained the sensor responses at a given time. As shown in Table 2, the sensor combinations were assigned numbers. Column numbers 2-6 are prototype 1a, 7-11 are prototype 2a, 12-16 are prototype 1b, 17-21 are prototype 2b, and 22-27 are the extra sensors.

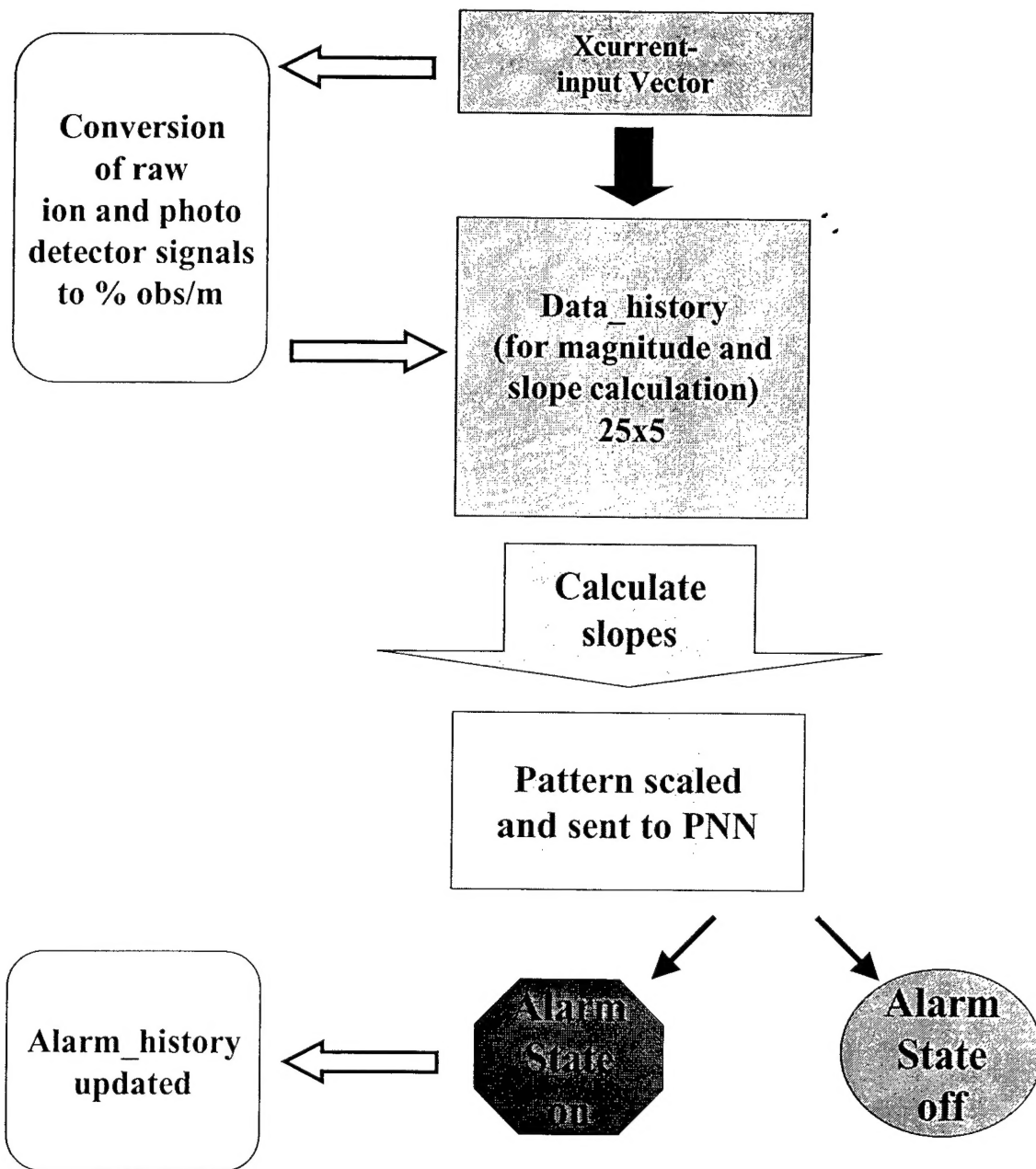


Figure 1. Flow chart for real-time PNN code: data_history and alarm_history are both inputs and outputs to code. Both variables have the most recent value added to the end of the vector or matrix and the first (oldest) value removed, thus maintaining their size.

Table 1. Test name, classification (1 = fire, 2 = nuisance) and description

| DESCRIPTION | TYPE | Class | BRIEF |
|-------------|------------------|-------|---|
| EWFD_001 | fire, flaming | 1 | Heptane |
| EWFD_002 | fire, flaming | 1 | Pipe insulation and fuel oil |
| EWFD_003 | fire, flaming | 1 | Oily rag, newspaper, cardboard in sm. trashcan |
| EWFD_004 | nuisance/ fire | 1 | Burning toast |
| EWFD_005 | fire, smoldering | 1 | Smoldering trash bag |
| EWFD_006 | nuisance | 2 | Cigarette smoking |
| EWFD_007 | fire, flaming | 1 | Flaming trashbag, TODCO wallboard |
| EWFD_008 | fire, flaming | 1 | Heptane |
| EWFD_009 | nuisance | 2 | Burning popcorn |
| EWFD_010 | fire, flaming | 1 | Electrical cable and pipe insulation |
| EWFD_011 | fire, smoldering | 1 | Smoldering electrical cable |
| EWFD_012 | nuisance | 2 | Arc welding |
| EWFD_013 | fire, flaming | 1 | Flaming bedding material |
| EWFD_014 | fire, flaming | 1 | Oily rag, newspaper, cardboard in sm. trashcan |
| EWFD_015 | nuisance | 2 | Normal toasting |
| EWFD_016 | fire, flaming | 1 | Small wood crib |
| EWFD_017 | fire, flaming | 1 | Trashcan and office chair |
| EWFD_018 | nuisance | 2 | Steel Cutting |
| EWFD_019 | fire, smoldering | 1 | Smoldering bedding material |
| EWFD_020 | fire, smoldering | 1 | Printed wire circuit board |
| EWFD_021 | fire | 1 | Brief wire overheat |
| EWFD_022 | fire, smoldering | 1 | Smoldering oily rag, newspaper, cardboard in sm. trashcan |
| EWFD_023 | fire, flaming | 1 | Pipe insulation and fuel oil |
| EWFD_024 | nuisance | 2 | Nylon rope |
| EWFD_025 | nuisance/ fire | 1 | Nylon rope into sm. trashcan |
| EWFD_026 | fire, smoldering | 1 | Smoldering trash bag |
| EWFD_027 | nuisance | 2 | Burning popcorn |
| EWFD_028 | nuisance | 2 | Steel grinding |
| EWFD_029 | fire, smoldering | 1 | Smoldering bedding material |
| EWFD_030 | nuisance/ fire | 1 | Burning toast |
| EWFD_031 | fire, flaming | 1 | Pipe insulation and heptane |
| EWFD_032 | nuisance | 2 | Cigarette smoking |
| EWFD_033 | fire, smoldering | 1 | Printed wire circuit board |
| EWFD_034 | fire | 1 | Brief wire overheat |
| EWFD_035 | fire, smoldering | 1 | Smoldering oily rag, newspaper, cardboard in sm. Trashcan |
| EWFD_038 | fire, flaming | 1 | Heptane |
| EWFD_039 | fire, flaming | 1 | Pipe insulation and fuel oil |
| EWFD_040 | fire, flaming | 1 | Flaming oily rag, newspaper, cardboard in sm. Trashcan |
| EWFD_041 | nuisance | 2 | Pop-Tarts™ toasting (8) |
| EWFD_042 | fire, smoldering | 1 | Smoldering oily rag, newspaper, cardboard in sm. Trashcan |
| EWFD_043 | fire, flaming | 1 | Heptane |
| EWFD_044 | fire, flaming | 1 | Heptane |
| EWFD_045 | fire, smoldering | 1 | Smoldering plastic bag of mixed trash |
| EWFD_046 | fire, flaming | 1 | Flaming bag of trash next to TODCO wallboard |
| EWFD_047 | nuisance | 2 | Burning popcorn |
| EWFD_048 | nuisance | 2 | Cutting Steel with acetylene torch |

| | | | |
|----------|------------------|---|--|
| EWFD_049 | nuisance | 2 | Cutting Steel with acetylene torch |
| EWFD_050 | fire, flaming | 1 | Electrical cable and pipe insulation next to flaming laundry pile |
| EWFD_051 | fire, smoldering | 1 | Long duration smoldering electrical cables |
| EWFD_052 | nuisance | 2 | Welding steel plate |
| EWFD_053 | fire, smoldering | 1 | Smoldering bedding |
| EWFD_054 | fire, flaming | 1 | Flaming bedding |
| EWFD_055 | fire, smoldering | 1 | Printed wire board (PWB) fire |
| EWFD_056 | fire, smoldering | 1 | PWB fire, with fire curtain covering alcove entrance in CSO |
| EWFD_057 | fire, smoldering | 1 | PWB fire, bad first PWB, new one installed 3.5 mins after first lost current. Powered up 10 minutes after first board was powered up |
| EWFD_058 | fire, smoldering | 1 | PWB fire |
| EWFD_059 | fire | 1 | Brief wire overheating |
| EWFD_060 | fire | 1 | BSI 6266 wire test |
| EWFD_061 | fire | 1 | BSI 6266 wire test |
| EWFD_062 | nuisance | 2 | Cooking shortening in wok |
| EWFD_063 | nuisance | 2 | Aerosol deodorants and hairspray |
| EWFD_064 | nuisance | 2 | Sweeping up a dropped bag of flour |
| EWFD_065 | nuisance | 2 | Pop-Tarts™ toasting (8) |
| EWFD_066 | nuisance | 2 | Normal Toasting (8 slices at a time, 16 total – lost power near end) |
| EWFD_067 | nuisance | 2 | Normal Toasting (8 slices at a time, 16 total) |
| EWFD_068 | nuisance | 2 | Cigarette smoking (15 total) |
| EWFD_069 | nuisance | 2 | Steel grinding nuisance |
| EWFD_070 | fire, flaming | 1 | Flaming oily rag, newspaper, cardboard in sm. Trashcan |
| EWFD_071 | fire, smoldering | 1 | Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN) |
| EWFD_072 | nuisance | 2 | Cooking Oil (used 100% vegetable oil, cast iron skillet and two-burner portable propane stove) |
| EWFD_073 | fire | 1 | Brief (30 sec) wire overheating |
| EWFD_074 | fire, smoldering | 1 | Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN) |
| EWFD_075 | nuisance | 2 | Steam generation (propane stove, cast iron skillet) |
| EWFD_076 | nuisance | 2 | Steam generation (skillet preheated with torch – red hot) |
| EWFD_077 | fire, smoldering | 1 | Smoldering electrical cable (LSTPNW-1½, MIL C-24643/52-01UN) |
| EWFD_080 | nuisance | 2 | Cooking oil. |
| EWFD_081 | nuisance | 2 | Steam Generation (preheated steel pan w/ torch) |
| EWFD_082 | nuisance | 2 | Steam generation (continuation of EWFD_081) |
| EWFD_083 | fire, smoldering | 1 | Smoldering Oily rag, newspaper, cardboard in sm. Trashcan |
| EWFD_084 | fire, smoldering | 1 | Smoldering bedding. |
| EWFD_085 | fire, smoldering | 1 | Long duration smoldering electrical cables (wrong cable) |
| EWFD_086 | fire, smoldering | 1 | Long duration smoldering electrical cables (wrong cable) |
| EWFD_087 | nuisance | 2 | Cigarette smoking |
| EWFD_088 | fire, smoldering | 1 | Long duration smoldering electrical cables |

Table 2. Sensor number and identity. Column numbers 2-6 are prototype 1a, 7-11 are prototype 2a, 12-16 are prototype 1b, 17-21 are prototype 2b, and 22-27 are the extra sensors

| Sensor | Column # |
|-----------------|----------|
| Elapsed time | 1 |
| ION#1(MIC) | 2 |
| Photo#1(%/ft) | 3 |
| CO(ppm) | 4 |
| RH(%) | 5 |
| CO2(ppm) | 6 |
| ION#4(MIC) | 7 |
| Photo#4(%/ft) | 8 |
| CO(ppm) | 9 |
| RH(%) | 10 |
| Temp(°C) | 11 |
| ION#2(MIC) | 12 |
| Photo#2(%/ft) | 13 |
| CO(ppm) | 14 |
| RH(%) | 15 |
| CO2(ppm) | 16 |
| ION#3(MIC) | 17 |
| Photo#3(%/ft) | 18 |
| CO(ppm) | 19 |
| RH(%) | 20 |
| Temp(°C) | 21 |
| O2(%) | 22 |
| H2S(ppm) | 23 |
| NO(ppm) | 24 |
| HC(ppm) | 25 |
| ION Chamber (V) | 26 |
| RION(V) | 27 |

3. PNN Real-Time Results

The comparison of the real-time prototype performance with the COTS (commercial off the shelf) smoke detectors is given in Table 3. The results of the real-time deployment of the PNN onboard the SHADWELL in Test Series 2 are better than the COTS ion, but not as good as the COTS photo. The overall correct classification of the two prototypes is similar. The fire detection rate for both prototypes 1 and 2 was greater than the COTS ion sensors and similar to the COTS photo. Prototype 1 had better real-time performance than the COTS for fire detection, 79% of fires correctly classified. Prototype 2 correctly classified 72% of the fire scenarios. The nuisance performance for prototypes 1 was poorer than the COTS with 40% correct classification versus 50% for the COTS ion sensor and 80% for the COTS photo sensor. Prototype 2 performed better than 1 for nuisances, correctly classifying 11 of 20 tests. The prototypes were also faster to alarm for fires than the COTS. In comparison to the COTS ion, the prototype 2 was slower to alarm than the COTS for 8 nuisance sources, and faster to alarm for only 3

nuisance sources. The increased speed of the prototypes increased their false alarm rate compared to the COTS photo. The prototype response time was considered similar where the alarm is within ± 30 seconds of the COTS response time.

Table 3. Results of PNN classification during the Test Series 2

| | Sensors | Total % Correct | Fires % Correct | Nuisances % Correct | # Fires Correct (29) | # Nuisances Correct (20) |
|--------------|-------------|--------------------|--------------------|------------------------|----------------------------|--------------------------------|
| Prototype 1: | 2 3 4 5 6 | 63.3 | 79.3 | 40.0 | 23 | 8 |
| Prototype 2: | 7 8 9 10 11 | 65.3 | 72.4 | 55.0 | 21 | 11 |
| COTS | Ion | 49.0 | 48.3 | 50.0 | 14 | 10 |
| | Photo | 77.6 | 75.9 | 80.0 | 22 | 16 |
| | Ion+Photo | 75.5 | 82.8 | 45.0 | 24 | 9 |

| | faster than ion | | | | | | | | | | | | | | | | | | similar to ion | | | | | | | | | | | | | | | | | | slower than ion | | | | | | | | | | | | | | | | | | faster than photo | | | | | | | | | | | | | | | | | | similar to photo | | | | | | | | | | | | | | | | | | slower than photo | | | | | | | | | | | | | | | | | | nuisances faster than ion | | | | | | | | | | | | | | | | | | similar to ion | | | | | | | | | | | | | | | | | | slower than ion | | | | | | | | | | | | | | | | | | nuisances faster than photo | | | | | | | | | | | | | | | | | | similar to photo | | | | | | | | | | | | | | | | | | slower than photo | | | | | | | | | | | | | | | | | | total fires faster | | | | | | | | | | | | | | | | | | total fires similar | | | | | | | | | | | | | | | | | | total fires other | | | | | | | | | | | | | | | | | | total nuisances slower | | | | | | | | | | | | | | | | | | total nuisances similar | | | | | | | | | | | | | | | | | | total nuisances other | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|--------------|-----------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-----------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|---------------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-----------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-----------------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|--------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|---------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|------------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-------------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|-----------------------|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|---|---|----|---|---|----|----|----|---|---|---|---|----|----|----|---|----|---|--|
| Prototype 1: | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | 4 | 4 | 11 | 5 | 0 | 10 | 10 | 12 | 9 | 8 | 0 | 9 | 11 | 14 | 11 | 4 | 20 | 5 | |

There were several problem areas during the real-time deployment of the PNN aboard the ex-USS SHADWELL. These include 1) a computational bottleneck that worsened as time increased, causing a decrease in the sampling frequency, 2) high baseline probability, 3) noisy probabilities, and 4) a calibration mismatch between the new Systems Sensor ionization detector (currently used in the prototypes) and the former Simplex ion detector (used during the collection of training data).

The first problem is characterized by the data acquisition system collecting data at a rate of 1 data point every 2 seconds, but after ≈ 2000 data points, the system requires 6 seconds between collection of data points. This delta time can represent a significant impediment to early fire warning and detection. The computational slowdown has been isolated and appears to be rooted in the data acquisition software's routines to call Matlab scripts. The instructions required for PNN analysis are contained in the Matlab scripts. The use of third party linear algebra function libraries (OptiVec for C++, Martin Sander Software Development) which removed the inefficient and problematic Matlab libraries has proved successful. This approach has solved the computational slowdown and has been tested over extended periods. The computational time required to process inputs

and produce a probability output for a given prototype has been reduced by a factor of 50 compared with LabVIEW calling a Matlab script. This method will be used in Test Series 3.

Apparently, the high temperature and relative humidities experienced during Test Series 2 resulted in high baseline probabilities when the 173-pattern training set was used and noisy probabilities when the 325-pattern training set was used. The PNN optimization section will describe the methods used to reduce these effects.

The most complex problem encountered was the mismatch of the System Sensor ionization data with that of the Simplex ion detectors. Originally it was thought that swapping one manufacturers' sensor for another brand would be possible, if both responses were converted to a standard such as percent obscuration per meter (%obs/m) as measured in UL standard 268 smoke box sensitivity tests. This turned out not to be the case, and an empirical correlation was required. Based on UL 268 smoke box tests a general empirical correlation was established between the Δ MIC reading of the ion detector and the corresponding %obs/ft measurements in the smoke box. This first attempt at a correlation produced ion detector outputs that were inconsistent with those obtained from the Simplex detectors for similar tests. Magnitudes and the temporal profiles were significantly different. Testing of the Simplex detectors side-by-side with the System Sensor detectors in a UL 268 smoke box was conducted. From these tests, an empirically derived linear correlation was determined and is given in equation 1:

$$y(x) = 0.0465x - 0.6572 \quad (1)$$

Where $y(x)$ is the % obs/ft and x is the System Sensor ionization detector Δ MIC reading. Plots showing the raw System Sensor data for several fires and the converted data (per Eqn. 1) are given in Figure 2. Using the linear correlation, rather than the fourth order polynomial used previously, results in a change in the scale of the plot. However, the shape remains identical in the conversion process with only a change in sensor magnitude as the result. The scaling changes places the System Sensor ion measurements in the same range as the Simplex ion detectors used in the training set.

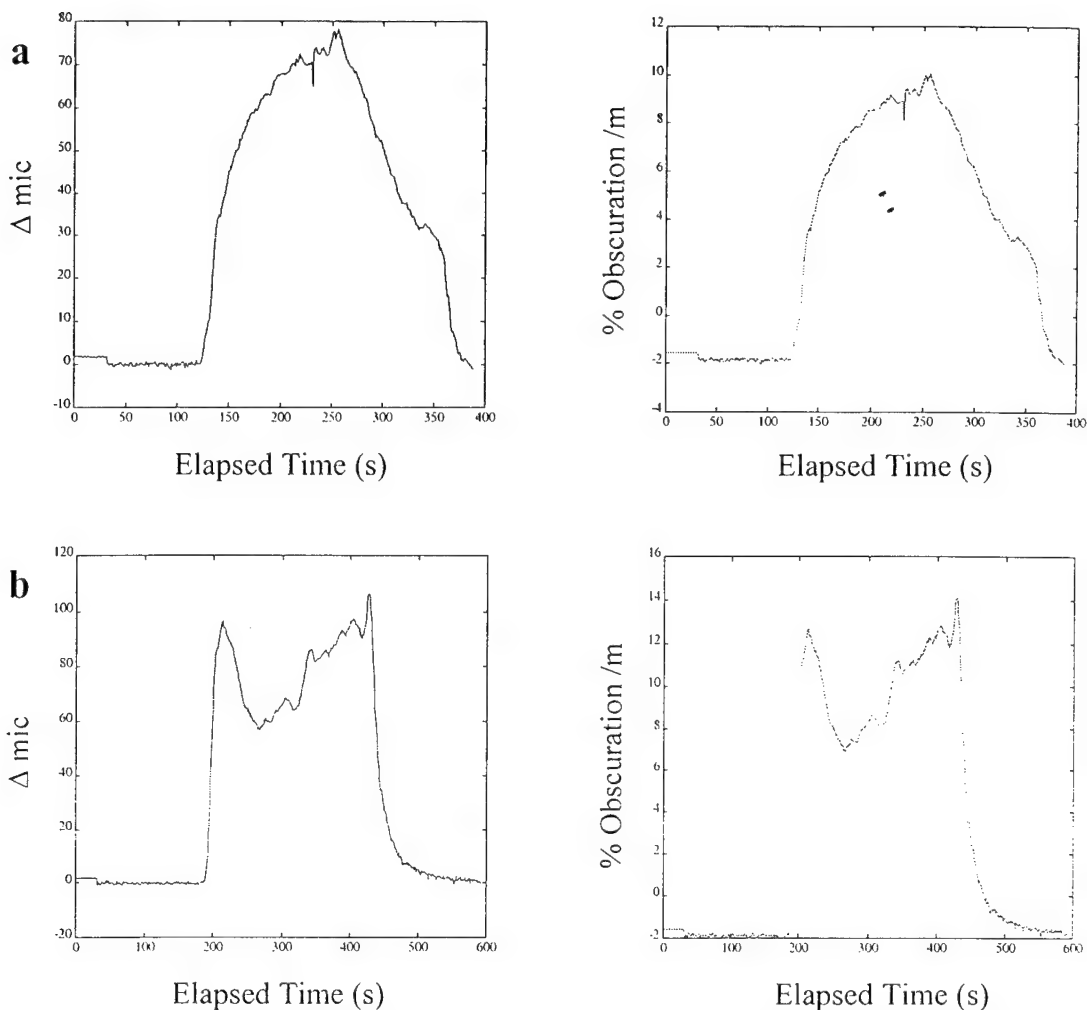


Figure 2. System Sensor ion detector output before and after conversion to % obs/m for two representative fire sources: a) flaming heptane, b) oily rag in trashcan fire.

4. PNN Optimization

The optimizations that began with the Test Series 1 data were continued with the addition of the Test Series 2 data. The first optimization was a modification to the training set to deal with the high baseline probability. Next the incompatibilities with the training and prediction data for the ion sensor were considered. Last a preliminary investigation into background subtraction was started. All experiments, unless stated otherwise, used the following parameters: the slope calculated over a 25-point region, no background subtraction, and the initial fourth order polynomial ion detector conversion from ΔMIC to %obs/ft. Both the ion and photo detector values were used in the PNN with units of %obs/m.

4.1 Training Set Optimization

Examination of the training sets used on the SHADWELL revealed some small errors in the data classifications. These problems were corrected and the data collected during Test Series 2 was reprocessed as shown in Table 4. The 325-pattern training set consisted of all the fire/nuisance sources and backgrounds from both the laboratory and August 1999 SHADWELL tests. The 173-pattern training set resulted from the removal of the alcohol and propane tests, 1 bad smoldering fire test, and a large number of backgrounds. The overall classification of the April data was not affected by these changes; however, the probability plots shown in Figures 3-9 are very different. The 325-pattern training set resulted in noisy output values, while the 173-pattern training set had very high baseline probabilities. A new training set was generated as a compromise that consisted of 200 patterns, the optimized set of 173 patterns along with 27 backgrounds from the August SHADWELL tests. The classification results are similar for all three training sets. The results of the experiments (Table 4) show the PNN classification results are almost identical with only the loss of one misclassified fire for prototype 2. The effects of the various training sets can be seen by comparing the probability plots. The plots from prototype 2 for all 49 experiments performed during Test Series 2 generated at the 11 % obs/m alarm time, for all three training set can be seen in Figures 3-9 a,b,c respectively. When comparing the modified 200-pattern training set to the 325-pattern set, the noise is reduced as shown in tests 38-51. The 200-pattern training set, compared to the 173-pattern training set, has lower baseline probabilities as shown in tests 48-88. Therefore, the 200-pattern training set produced the same classification results as the 173-training set, while the patterns generated had lower baseline probabilities similar to the 325-training set and noise levels similar to the 173-training set.

4.2 Ion Calibration

Using the new ion calibration, equation (1), Test Series 1 and 2 data were rerun with the modified 200-pattern training set as shown in Table 5 and Figure 10. The overall predictions for the prototypes (Table 5) changed only slightly with a loss of two fires for prototype 1, but a gain of one nuisance classified correctly for prototype 2. We expected a greater improvement, however, the falsely elevated results from the previous calibration allowed faster responses to fires.

The probability plots for eight of the experiments performed during the Test Series 2 generated at the 11% alarm time, comparing the old ion calibration to the new ion correlation can be seen in Figure 10 a and b respectively. The lower value of the ion sensor can be seen in the lower probabilities in tests 15, 41, and 9. Also the increased probability seen during venting in tests 9, 11, 64 also disappear with the corrected ion detector correlation. In addition, the problem caused by the incompatibility between the training set and prediction data where the PNN cannot calculate a probability (the gaps seen in tests 40, 46, and 50) disappear. The new correlation provides better agreement with the training set and will be used in future tests.

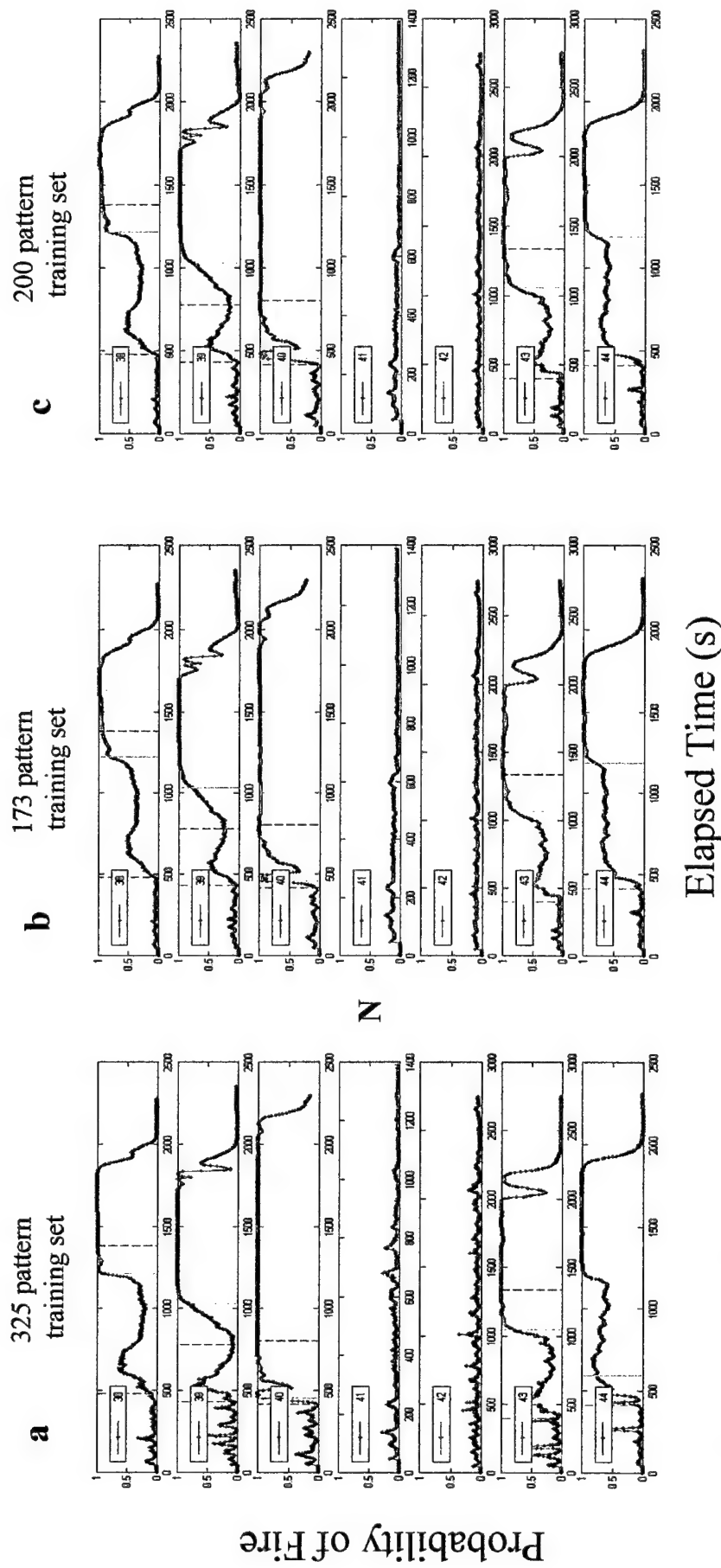


Figure 3. Probability versus elapsed time for Test Series 2, experiments 38-44 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

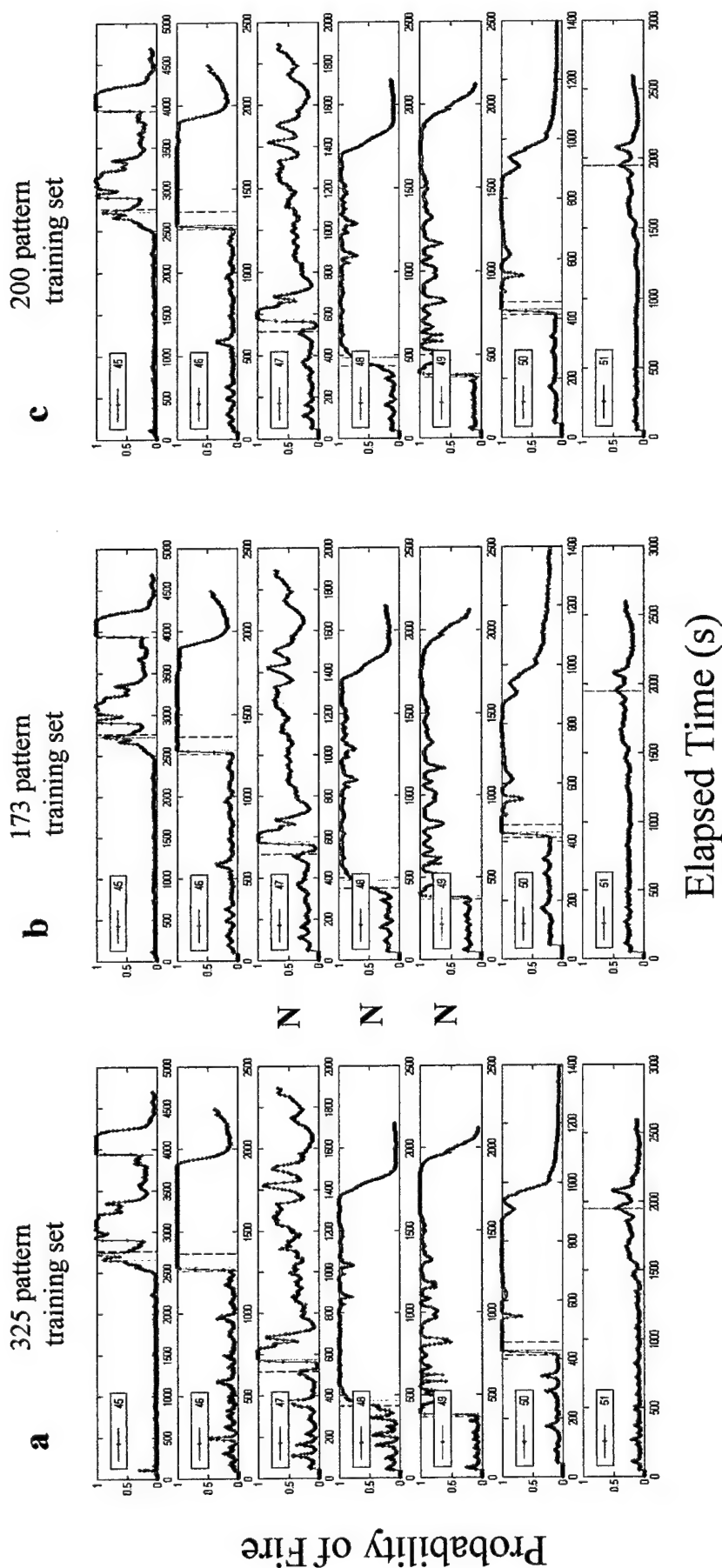


Figure 4. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 45-51 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

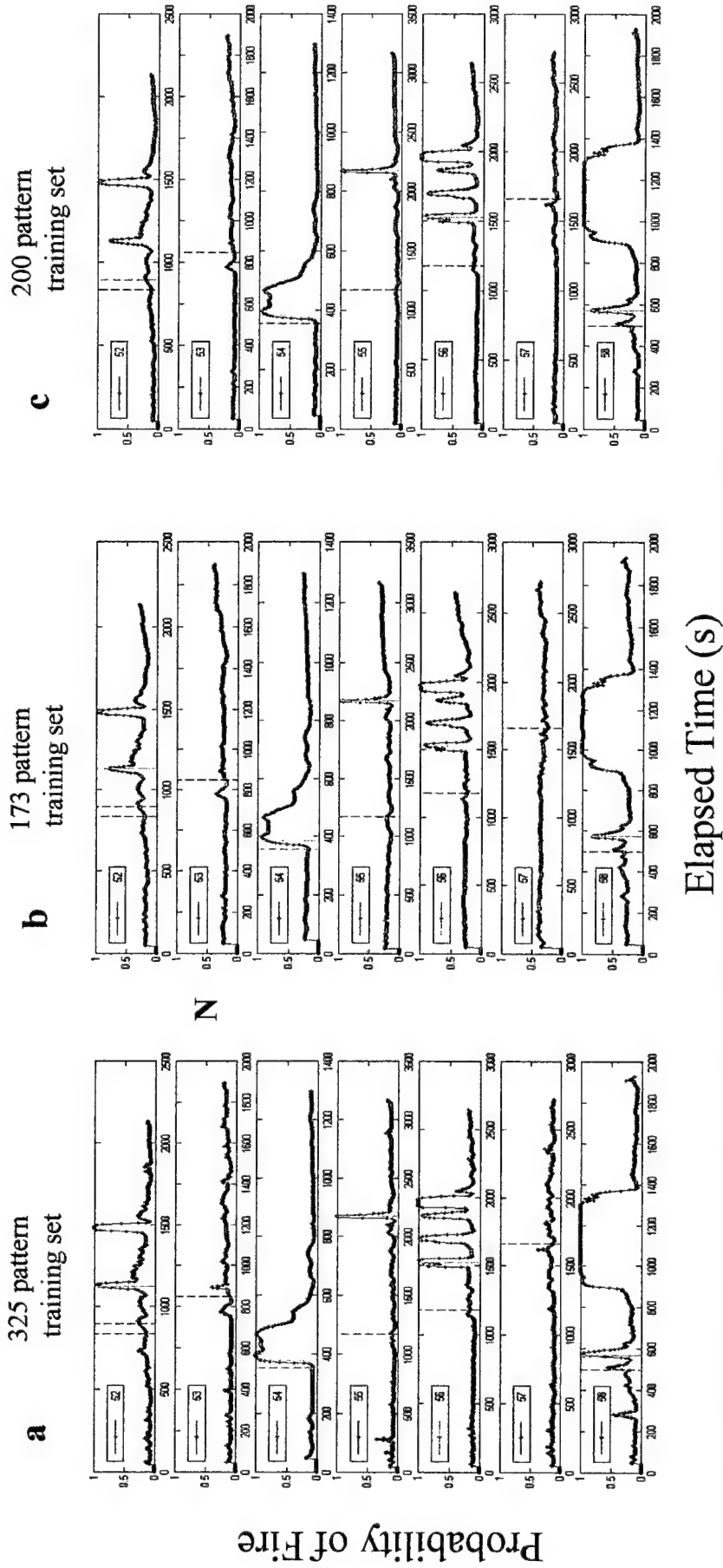


Figure 5. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 52-58 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

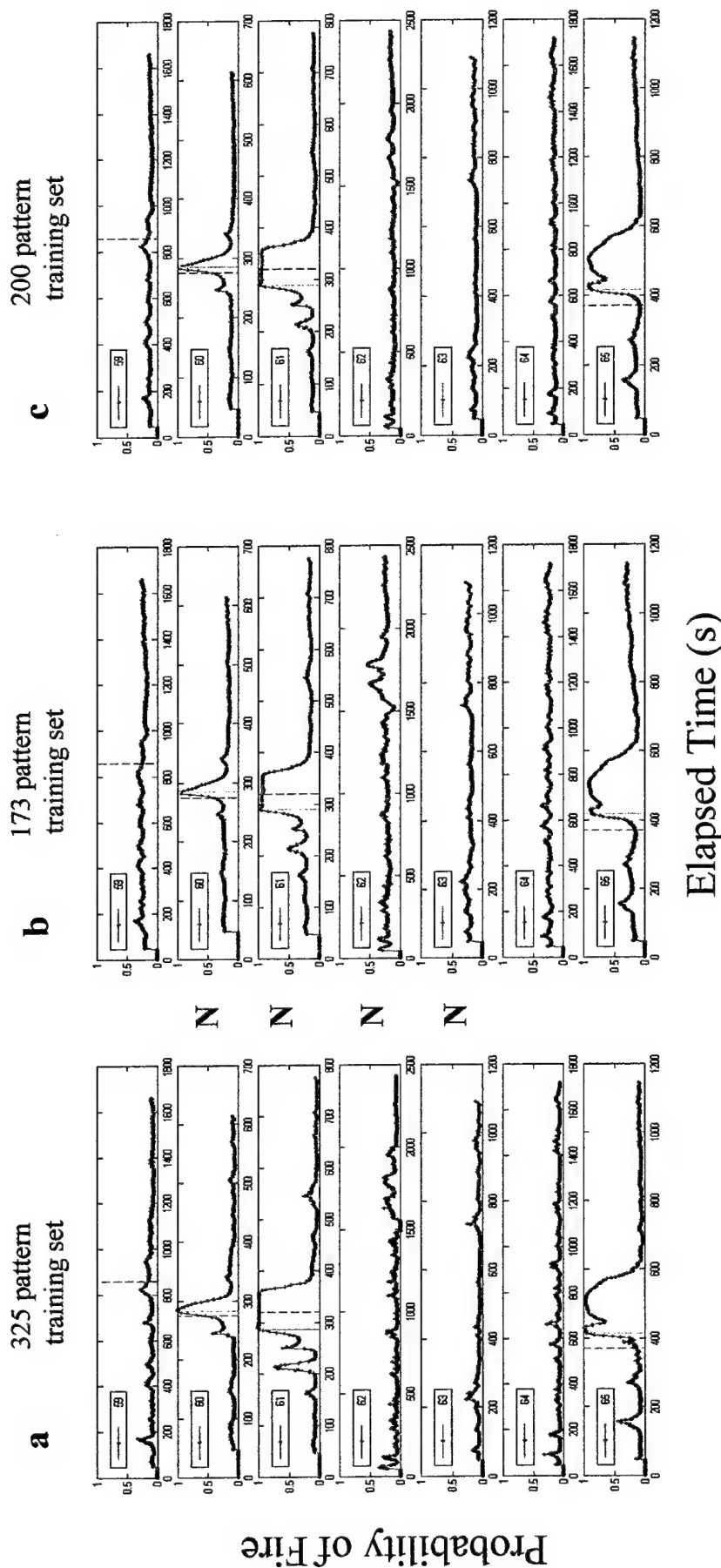


Figure 6. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 59-65 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

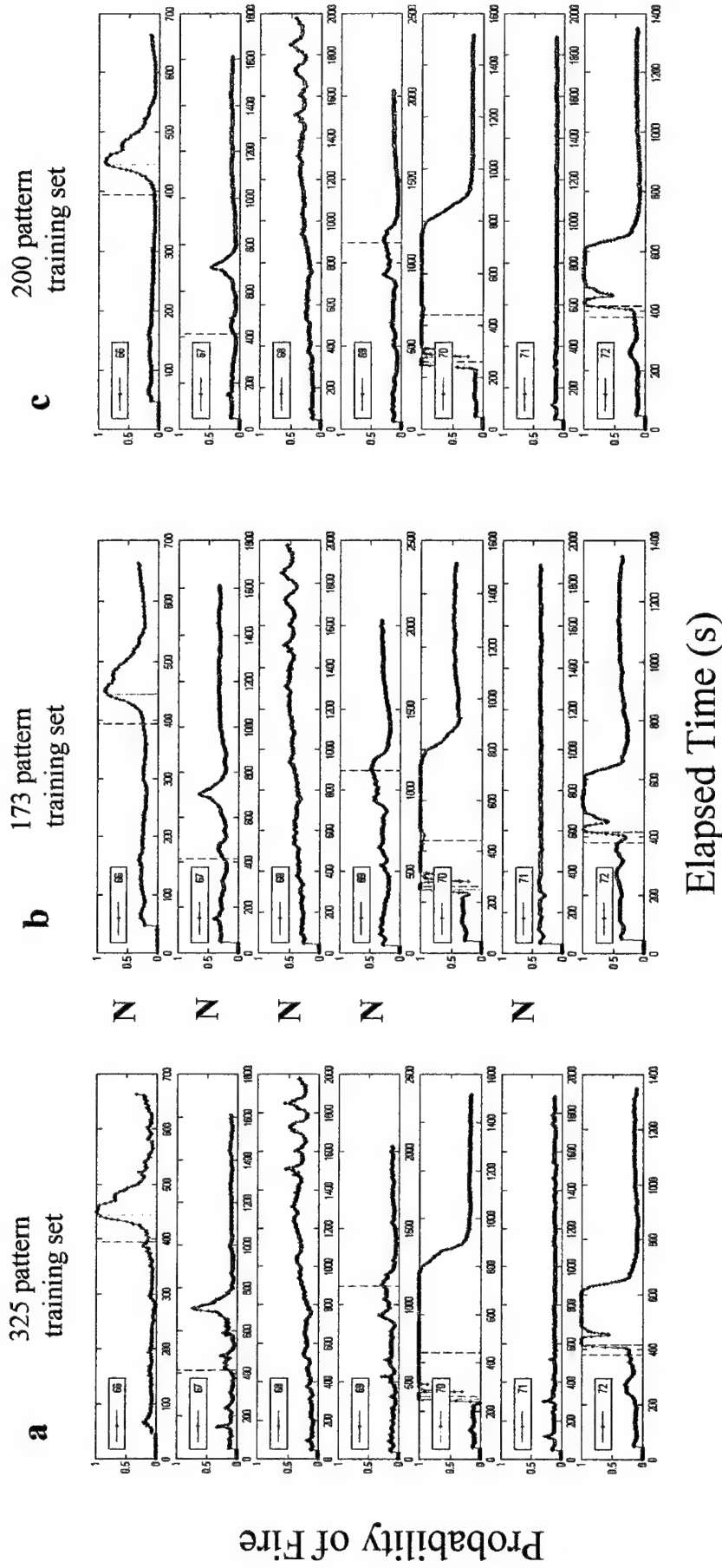


Figure 7. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 66-72 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an 'N'. Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

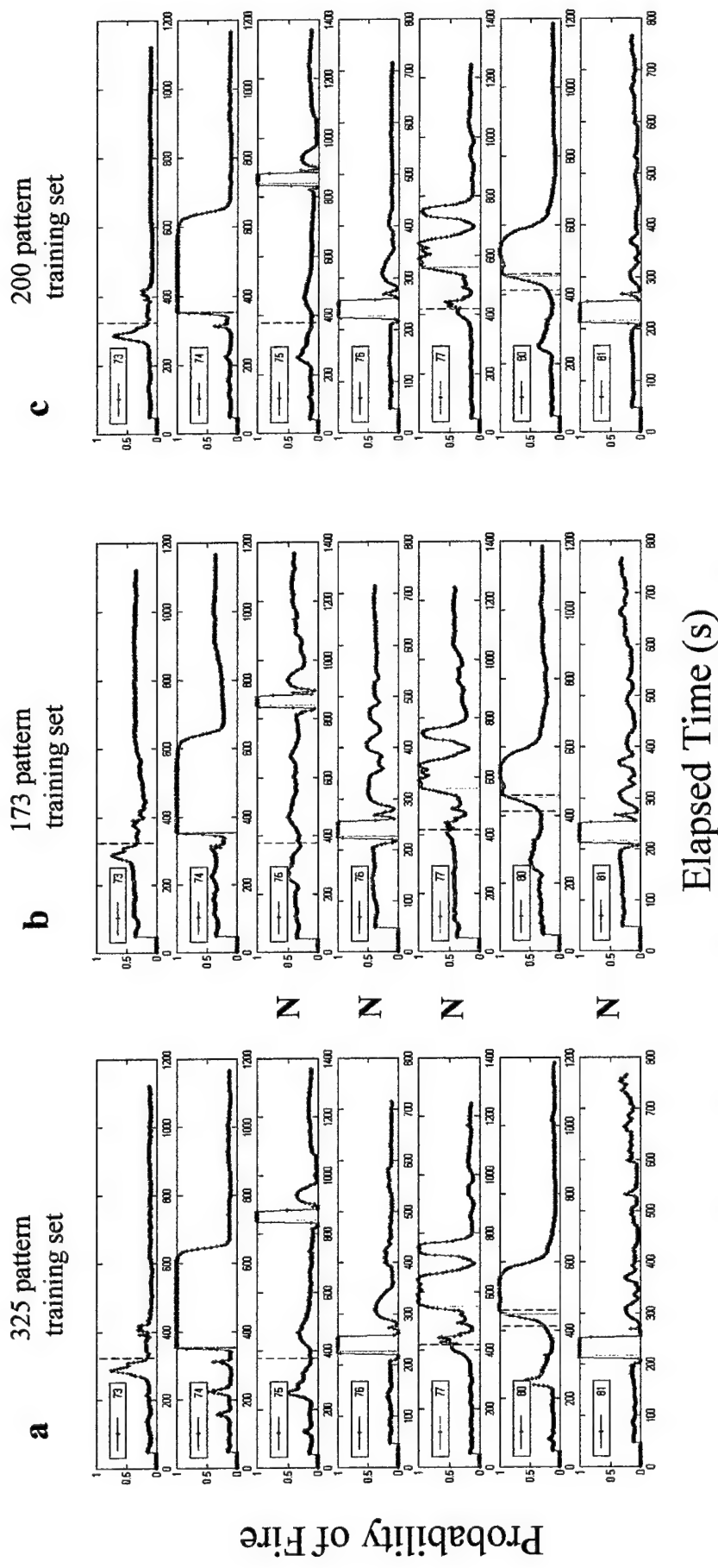


Figure 8. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 73-77, 80, 81 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

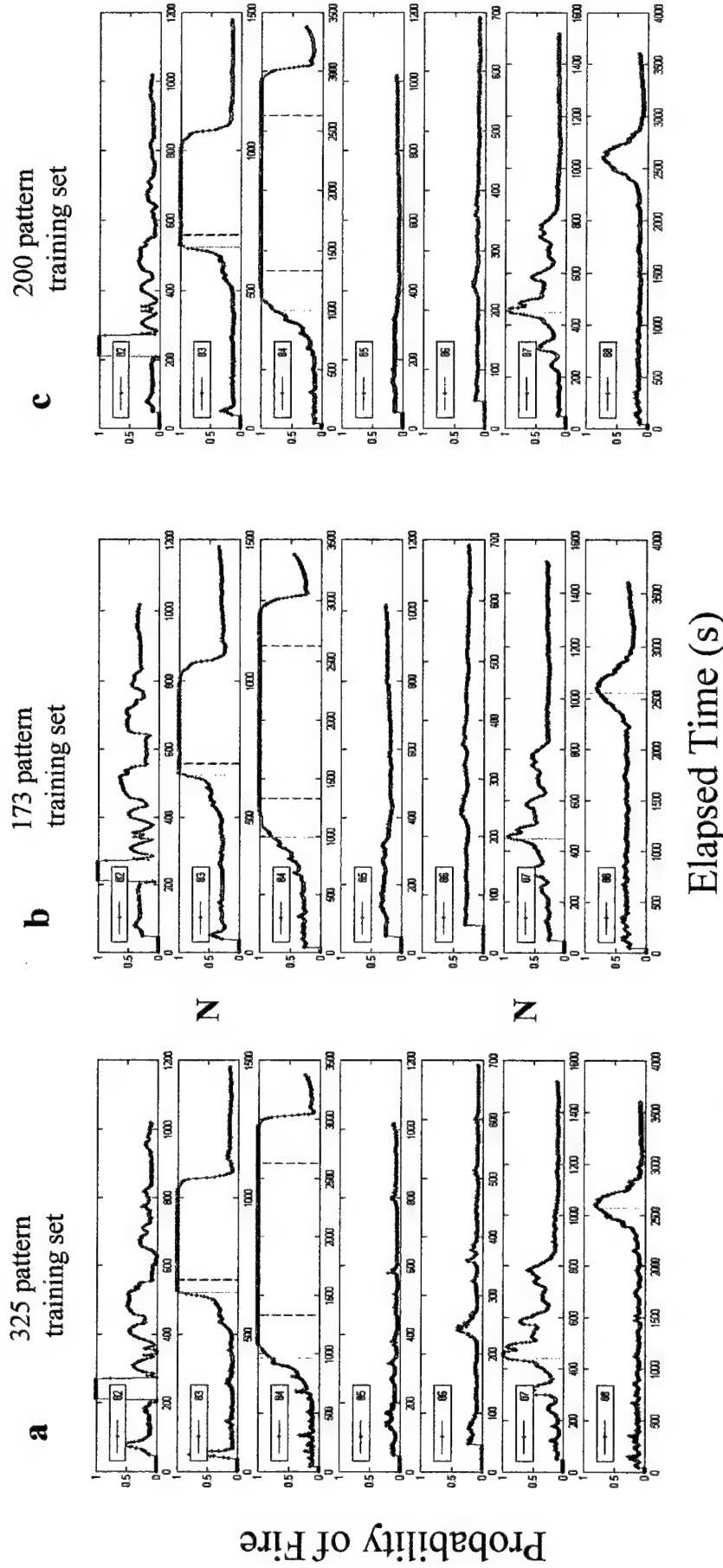


Figure 9. Probability versus elapsed time for Test Series 2, Prototype 2 experiments 82-88 (refer to Table 1 for test descriptions) generated at the 11 % alarm time, comparing a) the 325-pattern training set, b) the 173-pattern training set, and c) modified 200-pattern training set. Nuisance experiments are denoted with an "N". Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

Table 4. PNN classification comparison of training sets for prototype 1 and 2 using Test Series 2 Data

| DataSet | Prototype | Total % | | Fires % | | Nuisance % | | Total # | | Fires # | | Nuisance # | |
|-----------------------------------|-----------|---------|---------|---------|---------|------------|---------|---------|---------|---------|---------|------------|---------|
| | | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| Test Series 2 325 Training Set | 1A | 59.2 | 79.3 | 30.0 | 29 | 23 | 6 | 15 | 10 | 4 | 20 | 5 | 4 |
| | 2A | 55.1 | 69.0 | 35.0 | 27 | 20 | 7 | 10 | 13 | 6 | 12 | 7 | 10 |
| Test Series 2 200 Training Set | 1A | 61.2 | 79.3 | 35.0 | 30 | 23 | 7 | 14 | 9 | 6 | 18 | 6 | 5 |
| | 2A | 53.1 | 65.5 | 35.0 | 26 | 19 | 7 | 9 | 14 | 6 | 11 | 8 | 10 |
| Test Series 2 173 Training Set | 1A | 61.2 | 79.3 | 35.0 | 30 | 23 | 7 | 14 | 8 | 7 | 18 | 6 | 5 |
| | 2A | 55.1 | 69.0 | 35.0 | 27 | 20 | 7 | 10 | 13 | 6 | 11 | 8 | 10 |
| COTS | Ion | 49.0 | 48.3 | 50.0 | 24 | 14 | 10 | | | | | | |
| | Photo | 77.6 | 75.9 | 80.0 | 38 | 22 | 16 | | | | | | |
| | Ion+Photo | 75.5 | 82.8 | 45.0 | 37 | 24 | 13 | | | | | | |

Table 5. PNN classification comparison of old and new ion correlation for prototype 1 and 2 using Test Series 1 and 2 Data

| Test Series 1 and 2 Data | Prototype | Total % | | Fires % | | Nuisance % | | Total # | | Fires # | | Nuisance # | |
|---|-----------|---------|---------|---------|---------|------------|---------|---------|---------|---------|---------|------------|---------|
| | | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |
| 200 Training Set old ion correlation | 1A | 69.0 | 83.6 | 41.4 | 58 | 46 | 12 | 22 | 24 | 9 | 33 | 12 | 10 |
| | 2A | 61.9 | 74.5 | 37.9 | 52 | 41 | 11 | 16 | 30 | 9 | 24 | 16 | 15 |
| 200 Training Set new ion correlation | 1A | 66.7 | 80.0 | 41.4 | 56 | 44 | 12 | 20 | 23 | 12 | 29 | 15 | 11 |
| | 2A | 63.1 | 74.5 | 41.4 | 53 | 41 | 12 | 17 | 29 | 9 | 25 | 15 | 12 |
| COTS | Ion | 56.0 | 58.2 | 51.7 | 47 | 32 | 15 | | | | | | |
| | Photo | 77.4 | 78.2 | 75.9 | 65 | 43 | 22 | | | | | | |
| | Ion+Photo | 71.4 | 87.3 | 41.4 | 60 | 48 | 12 | | | | | | |

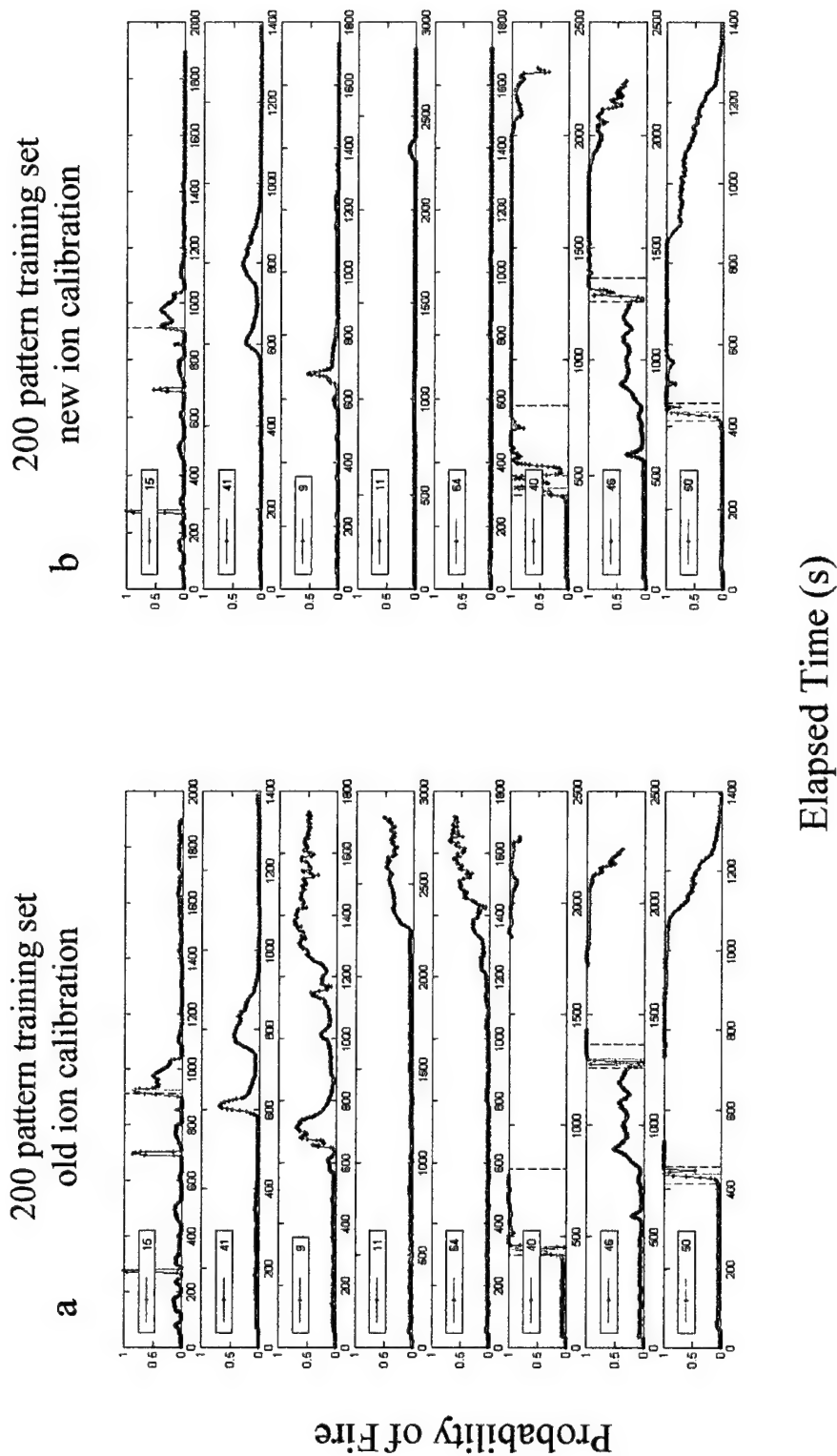


Figure 10. Probability versus elapsed time for Test Series 2 experiments 15, 41, 9, 11, 64, 40, 46, 50 (refer to Table 1 for test descriptions) generated at the 11 % alarm time with the modified 200-pattern training set, comparing a) the old ion correlation and b) the new ion correlation. Solid green line = PNN alarm time, dashed red line = COTS Ion alarm time, and dashed black line = COTS Photo alarm time.

4.3 Sensor Optimization

The PNN was modified and optimized for increased nuisance detection relative to its real-time performance during Test Series 1 and 2. The optimization was done in several ways beginning with the correction of the real-time code described in the previous section. The real-time code used for optimization was identical to the modified code (used in the Test Series 2) with the exception of provisions (if statements) for proper preprocessing of various sensor values. This was done in order to allow testing of alternative sensor combinations. Similar to the algorithm for real-time analysis, the slope was calculated over a 25-point region (number of rows in data_history), no background subtraction was performed, and the System Sensor ion detector had a correlation conversion from ΔMIC to % obs/ft, then to % obs/m, and the photo detector had a conversion from % obs/ft to % obs/m.

Using the modified 200 training set, 540 experiments were run to determine the best combination of sensors. The experiments varied 54 sensor combinations (see Table 6), along with training sets generated using the 11%, 1.63%, 0.82%, 11% + 1.63% and 11% + 0.82% COTS photoelectric alarm times. The third condition tested was the data averaging size for the magnitude, both 10 and 25-point averages were used along with a 25-point slope average. The original method involved a 10-point magnitude averaging, but recent tests used a 25-point average. The data used in the training set used 4 second intervals and the more recent data collection varied from 2-8 second intervals, over the course of a test. The PNN code was modified to allow for the selection of the magnitude/slope averaging in the prediction set.

Table 6. Sensor combinations used in optimization of Test Series 1 and 2 Data Set (see key given in Table 2)

| | | |
|------------|-------------|----------------|
| 2 3 4 | 7 8 9 | 26 3 4 5 6 |
| 2 3 5 | 7 8 10 | 26 8 9 10 11 |
| 2 3 6 | 7 8 11 | 27 3 4 5 6 |
| 2 4 5 | 7 9 10 | 27 8 9 10 11 |
| 2 4 6 | 7 9 11 | 26 4 |
| 2 5 6 | 7 10 11 | 26 6 |
| 3 4 5 | 8 9 10 | 26 4 6 |
| 3 4 6 | 8 9 11 | 27 4 |
| 3 5 6 | 8 10 11 | 27 6 |
| 4 5 6 | 9 10 11 | 27 4 6 |
| 2 3 4 5 | 7 8 9 10 | 2 4 6 24 25 |
| 2 3 4 6 | 7 8 9 11 | 2 3 4 23 |
| 2 3 5 6 | 7 8 10 11 | 2 3 4 23 25 |
| 2 4 5 6 | 7 9 10 11 | 2 4 6 23 25 |
| 3 4 5 6 | 8 9 10 11 | 2 4 6 22 23 25 |
| 2 3 6 11 | 7 8 11 6 | 4 22 23 25 |
| 2 3 4 6 11 | 7 8 9 11 6 | 2 3 4 5 6 11 |
| 2 3 4 5 6 | 7 8 9 10 11 | 7 8 9 10 11 6 |

4.3.1 Classification Performance

A representative set of classification results using various sensor combinations and training sets, is given in Tables 7 and 8. The data in Table 7 lists the top combinations when sorting by the best overall classification and then by nuisance classification. The data in Table 8 lists the top combinations when sorting by the best nuisance classification and then by overall classification. The results for prototype 1 and 2 are included at the bottom of each list for comparison.

The classification results using subsets of prototype 1 and 2 have shown marked improvement over the 5-sensor prototype. The highest performing sensor combinations had a better overall performance than either prototype, 73-77% vs. 63-68% respectively. When judging the results by nuisance classification, the original prototypes were beaten by 14-27%, approaching the best results from the COTS (see Table 5). The misclassified fires for the best set, prototypes 1 and 2 and the COTS Photo are given in Table 9.

4.3.2 Speed Performance

In addition to the classification performance, the speed of PNN classification relative to COTS detectors was gauged using several criteria. The additional criteria used measured time to alarm for the sensor arrays compared to the COTS ion and photo detectors. The preferred performance observed an increase in the number of fires faster and the number of nuisances slower than the COTS ion or photo detectors. Slower alarm times for fires or faster alarm times for nuisance sources was not a desirable response. The number of fires similar to ion and the number of nuisances similar to photo are determined by counting those experiments where the prototype response is within ± 30 seconds of the COTS response time. The number of fires similar to COTS and the number of nuisances similar to COTS are additional measures with which to measure PNN performance. These figures of merit are given in Tables 7 and 8.

The new sensor combinations in general had better speed for classifying a fire compared to the original prototypes. The subsets show faster detection times for fires while not increasing the false alarm rate. The best subsets improved detection relative to COTS detectors by up to 10 fires compared to the original prototypes. When comparing those combinations with the best nuisance classification, the subsets show great improvement with little loss of fire classification. An improvement over the COTS detectors was also observed for nuisance sources with 2-8 events slower to alarm than COTS. The subsets are slower to alarm than the COTS ion, but the COTS photo consistently performed better than the prototypes or subsets.

Table 7. Representative PNN classification results of optimization of sensor combinations, training set alarm times and magnitude size averaging (sorted by %total/%nuisance)

| magnitude size average | Training set alarm time | Sensors | Total % | | Fires % | | Nuisance | | Total # Correct | Fires # | | Nuisance | | # Correct | Total # Correct | Fires faster than ion | fires similar to ion | fires faster than photo | fires slower than photo | nuisances faster than ion | nuisances slower than ion | nuisances faster than photo | nuisances slower than photo | total fires faster | total fires similar | total nuisances slower | total nuisances similar | total nuisances other |
|------------------------------|-------------------------------|-------------|---------|---------|---------|---------|----------|---------|--------------------|----------|---------|----------|----|-----------|--------------------|-----------------------|----------------------|-------------------------|-------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|--------------------|---------------------|------------------------|-------------------------|-----------------------|
| | | | Correct | Correct | Correct | Correct | %Correct | Correct | | %Correct | Correct | Correct | | | | | | | | | | | | | | | | |
| 10 | 11% | 2 3 6 11 | 77.4 | 90.9 | 51.7 | 65 | 50 | 15 | 27 | 21 | 7 | 34 | 10 | 11 | 6 | 16 | 7 | 3 | 15 | 11 | 19 | 16 | 1 | 17 | 1 | 16 | 12 | |
| 25 | 11% | 7 8 11 | 76.2 | 85.5 | 58.6 | 64 | 47 | 17 | 21 | 23 | 11 | 25 | 18 | 12 | 14 | 3 | 2 | 20 | 7 | 9 | 24 | 22 | 1 | 20 | 8 | | | |
| 25 | 11% | 2 3 6 11 | 76.2 | 89.1 | 51.7 | 64 | 49 | 15 | 26 | 22 | 7 | 33 | 10 | 12 | 7 | 16 | 6 | 3 | 16 | 10 | 18 | 19 | 18 | 1 | 17 | 11 | | |
| 10 | 11% | 7 8 11 | 75.0 | 87.3 | 51.7 | 63 | 48 | 15 | 22 | 23 | 10 | 28 | 16 | 11 | 10 | 14 | 5 | 2 | 18 | 9 | 11 | 24 | 20 | 0 | 19 | 10 | | |
| 25 | 11% | 7 8 11 6 | 73.8 | 81.8 | 58.6 | 62 | 45 | 17 | 21 | 24 | 10 | 23 | 21 | 11 | 12 | 14 | 3 | 2 | 20 | 7 | 8 | 27 | 20 | 1 | 20 | 8 | | |
| 10 | 1.63% | 7 8 9 11 6 | 73.8 | 94.5 | 34.5 | 62 | 52 | 10 | 34 | 21 | 0 | 45 | 8 | 2 | 4 | 9 | 16 | 1 | 10 | 18 | 30 | 23 | 2 | 0 | 10 | 19 | | |
| 25 | 11% | 26 4 6 | 72.6 | 83.6 | 51.7 | 61 | 46 | 15 | 27 | 27 | 1 | 36 | 11 | 8 | 7 | 10 | 12 | 2 | 15 | 12 | 22 | 24 | 9 | 1 | 14 | 13 | | |
| 25 | 11% | 26 4 6 | 72.6 | 83.6 | 51.7 | 61 | 46 | 15 | 27 | 25 | 3 | 34 | 13 | 8 | 7 | 10 | 12 | 2 | 15 | 12 | 21 | 23 | 11 | 1 | 15 | 13 | | |
| 10 | 11% | 26 3 4 5 6 | 72.6 | 83.6 | 51.7 | 61 | 46 | 15 | 26 | 21 | 8 | 34 | 12 | 9 | 5 | 12 | 12 | 2 | 15 | 12 | 20 | 18 | 17 | 0 | 14 | 13 | | |
| 10 | 11% | 2 3 6 | 72.6 | 85.5 | 48.3 | 61 | 47 | 14 | 24 | 22 | 9 | 33 | 11 | 11 | 6 | 16 | 7 | 3 | 15 | 11 | 18 | 18 | 19 | 1 | 16 | 12 | | |
| 25 | 11% | 2 3 4 5 6 | 66.7 | 80.0 | 41.4 | 56 | 44 | 12 | 20 | 23 | 12 | 29 | 15 | 11 | 9 | 10 | 10 | 3 | 12 | 14 | 13 | 20 | 22 | 2 | 12 | 15 | | |
| 25 | 11% | 7 8 9 10 11 | 63.1 | 74.5 | 41.4 | 53 | 41 | 12 | 17 | 29 | 9 | 25 | 15 | 15 | 12 | 9 | 8 | 3 | 14 | 12 | 10 | 24 | 21 | 1 | 15 | 13 | | |

Table 8. Representative PNN classification results of optimization of sensor combinations, training set alarm times and magnitude size averaging (sorted by %nuisance (%total))

| magnitude size average | Training set alarm time | Sensors | Total % | | Fires % | | Nuisance % | | Total # Correct | Fires # | | Nuisance # | | magnitude size averaging (sorted by performance / accuracy) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|------------------------|-------------------------|---------|---------|---------|---------|---------|------------|---------|-----------------|---------|---------|------------|---------|---|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|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| | | | Correct | Correct | Correct | Correct | Correct | Correct | | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | 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Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct |

Table 9. Misclassified Fire/Nuisance Sources

| EWFD Test # | Description | EWFD Test # | Description |
|-------------------------|---------------------------------|------------------------------|---------------------------------|
| 25/25 11% | Prototype 1 | 25/25 11% | Prototype 2 |
| 011, 071, 085, 086, 088 | Smoldering Electrical Cable | 011, 051, 071, 085, 086, 088 | Smoldering Electrical Cable |
| 060, 061 | Wire Test | 021, 059, 073 | Wire Test |
| 020, 033, 057, 058 | PWB | 020, 033, 057 | PWB |
| | | 042 | Smoldering Oily Rag in trashcan |
| 012, 052 | Arc Welding | 053 | Smoldering Bedding |
| 027, 047 | Burning Popcorn | | |
| 018, 048, 049 | Steel Cutting | 012, 052 | Arc Welding |
| 006, 087 | Cigarette Smoking | 009, 027, 047 | Burning Popcorn |
| 063 | Aerosol deodorants/hairspray | 018, 048, 049 | Steel Cutting |
| 065 | Poptarts | 006, 087 | Cigarette Smoking |
| 069 | Steel Grinding | 065 | Poptarts |
| 072 | cooking oil | 072, 080 | cooking oil |
| 075, 076, 081, 082 | Steam | 075, 076, 081, 082 | Steam |
| EWFD Test # | Description | EWFD Test # | Description |
| 25/25 11% | 7 8 11 | | COTS Photo |
| 071, 085, 086 | Smoldering Electrical Cable | 011, 071, 085, 086, 088 | Smoldering Electrical Cable |
| 034, 059 | Wire Test | 034 | Wire Test |
| 057 | PWB | 001, 044 | Heptane |
| 042 | Smoldering Oily Rag in trashcan | 042 | Smoldering Oily Rag in trashcan |
| 053 | Smoldering Bedding | 013, 054 | Flaming Bedding |
| | | 025 | nylon rope into sm trash can |
| 012, 052 | Arc Welding | | |
| 009, 027, 047 | Burning Popcorn | 027, 047 | Burning Popcorn |
| 018, 048, 049 | Steel Cutting | 012, 052 | Arc Welding |
| 065 | Poptarts | 032 | Cigarette Smoking |
| 072, 080 | cooking oil | 072, 080 | Cooking oil |
| 066 | toasting | | |

4.4 Background Subtraction

Background subtraction was tested by removing all backgrounds from the 200-pattern training set leaving only 140 patterns. These patterns were background subtracted using the first 30 seconds of each test to determine the baseline reading. The prediction set was also background subtracted again using the first 30 seconds to determine the baseline, with the exception of the ion and photo detector which were background subtracted when the data was collected. Using the background subtracted 140-pattern training set, 288 experiments were run using 48 sensor combinations and 3 training set alarm conditions (11, 1.63, and 0.82%). Both the 10 and 25-point data averaging size was used for the magnitude, along with a 25-point slope average. The PNN code was modified from the above sensor optimization to allow for the background subtraction of the sensor values, again with the exception of the ion and photo detectors, in the prediction set. The best results along with the results for prototypes 1 and 2 are listed in Tables 10 and 11, sorted by total percent correct and nuisance percent correct, respectively.

For both prototypes, background subtraction experiments were performed with the same parameters, 11% training set alarm times / 25:25 magnitude/slope data averaging, as the non-background subtracted for comparison. The overall correct classification of the data sets did not change significantly, however, prototype 1 showed a 7% improvement in nuisance classification and misclassified 8% more of the fires. Prototype 2 on the other hand showed 17% increase in nuisance detection with no difference in fire classification. The results are better than the COTS ion and worse than the COTS photo.

The classification performance of the subsets of the original prototypes showed a 5% improvement over the background subtracted results of the original 5 sensor prototypes. The improvement was mostly in the number of fires classified correctly. The speed of the classification relative to the COTS detectors also improved with 5-10 fires identified faster than the original prototypes. As seen in Table 11, good nuisance source rejection results in reduced speed and fewer fires correct. The best overall performance observed in Table 10 is from ION, Photo, and CO₂ (sensors: 7 8 6) using 11% obs/m for the alarm time and a 25 point magnitude average. The best nuisance source rejection was also observed for ION, Photo, and CO₂, using the same 11% obs/m for the alarm time and a 25 point magnitude average. The best classification performance while maintaining a fast detection speed relative to the COTS detectors was observed with ION, Photo, CO, and CO₂ (sensors: 7 8 9 6) using the 1.63% obs/m for the alarm time and a 10 point magnitude average. The types of fires misclassified by this sensor array are given in Table 12.

These preliminary investigations into background subtraction look promising and would solve many problems associated with different environmental conditions. When background subtraction is used, it is no longer necessary to include a large number of backgrounds in the training set. The need to represent extreme conditions should be reduced.

Table 10. Representative PNN classification results of optimization of sensor combinations, training set alarm times and magnitude size averaging using background subtraction (sorted by %total/%nuisance)

| magnitude size average | Training set alarm time | Sensors | Total % | | Fires % | | Nuisance | | Total # | | Fires # | | Nuisance | | # Correct | Fires faster than ion | Fires slower than ion | Fires similar to ion | Fires faster than photo | Fires slower than photo | nuisances faster than ion | nuisances slower than ion | nuisances faster than photo | nuisances slower than photo | total fires faster | total fires similar | total fires other | total nuisances faster | total nuisances similar | total nuisances slower | total nuisances other |
|------------------------------|-------------------------------|-------------|---------|---------|---------|----------|----------|----------|---------|----------|---------|----|----------|----|-----------|-----------------------|-----------------------|----------------------|-------------------------|-------------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|--------------------|---------------------|-------------------|------------------------|-------------------------|------------------------|-----------------------|
| | | | Correct | Correct | Correct | %Correct | Correct | %Correct | Correct | %Correct | | | | | | | | | | | | | | | | | | | | | |
| 25 | 11% | 7 8 6 | 76.2 | 74.5 | 79.3 | 79.3 | 64 | 41 | 23 | 13 | 29 | 13 | 17 | 17 | 13 | 14 | 2 | 4 | 2 | 2 | 27 | 26 | 1 | 25 | 3 | | | | | | |
| 25 | 11% | 7 8 11 | 75.0 | 74.5 | 75.9 | 75.9 | 63 | 41 | 22 | 12 | 29 | 14 | 16 | 19 | 20 | 12 | 5 | 20 | 4 | 2 | 25 | 28 | 2 | 22 | 5 | | | | | | |
| 25 | 11% | 7 8 11 6 | 75.0 | 74.5 | 75.9 | 75.9 | 63 | 41 | 22 | 12 | 29 | 14 | 18 | 18 | 19 | 12 | 5 | 20 | 4 | 2 | 25 | 28 | 2 | 22 | 5 | | | | | | |
| 10 | 11% | 7 8 6 | 75.0 | 78.2 | 69.0 | 69.0 | 63 | 43 | 20 | 15 | 27 | 13 | 20 | 20 | 15 | 12 | 3 | 4 | 3 | 22 | 4 | 4 | 27 | 24 | 1 | 23 | 5 | | | | |
| 10 | 1.63% | 7 8 9 6 | 75.0 | 81.8 | 62.1 | 62.1 | 63 | 45 | 18 | 23 | 27 | 5 | 36 | 12 | 7 | 8 | 11 | 10 | 3 | 16 | 10 | 18 | 25 | 12 | 2 | 16 | 11 | | | | |
| 10 | 1.63% | 7 8 9 | 75.0 | 87.3 | 51.7 | 51.7 | 63 | 48 | 15 | 26 | 24 | 5 | 37 | 12 | 6 | 8 | 10 | 11 | 1 | 17 | 11 | 19 | 25 | 11 | 0 | 17 | 12 | | | | |
| 25 | 1.63% | 7 8 9 | 75.0 | 87.3 | 51.7 | 51.7 | 63 | 48 | 15 | 25 | 26 | 4 | 35 | 13 | 7 | 8 | 13 | 8 | 1 | 17 | 11 | 17 | 28 | 10 | 0 | 17 | 12 | | | | |
| 10 | 1.63% | 7 8 9 11 | 73.8 | 81.8 | 58.6 | 58.6 | 62 | 45 | 17 | 23 | 27 | 5 | 35 | 13 | 7 | 8 | 11 | 10 | 3 | 15 | 11 | 17 | 26 | 12 | 2 | 15 | 12 | | | | |
| 10 | 11% | 2 4 6 | 72.6 | 74.5 | 69.0 | 69.0 | 61 | 41 | 20 | 18 | 30 | 7 | 29 | 12 | 14 | 10 | 13 | 6 | 4 | 18 | 7 | 14 | 23 | 18 | 3 | 18 | 8 | | | | |
| 25 | 11% | 7 8 9 | 72.6 | 74.5 | 69.0 | 69.0 | 61 | 41 | 20 | 15 | 31 | 9 | 22 | 18 | 15 | 12 | 13 | 4 | 4 | 19 | 6 | 7 | 27 | 21 | 2 | 20 | 7 | | | | |
| 25 | 11% | 2 3 4 5 6 | 64.3 | 72.7 | 48.3 | 48.3 | 54 | 40 | 14 | 20 | 25 | 10 | 24 | 19 | 12 | 10 | 8 | 11 | 3 | 13 | 13 | 13 | 22 | 20 | 2 | 13 | 14 | | | | |
| 25 | 11% | 7 8 9 10 11 | 69.0 | 74.5 | 58.6 | 58.6 | 58 | 41 | 17 | 17 | 30 | 8 | 22 | 16 | 17 | 12 | 10 | 7 | 4 | 16 | 9 | 7 | 28 | 20 | 2 | 17 | 10 | | | | |

Table 11. Representative PNN classification results of optimization of sensor combinations, training set alarm times and magnitude size averaging using background subtraction (sorted by %nuisance/%total)

| magnitude | Training set alarm | Sensors | Total % Correct | Fires % Correct | Nuisance %Correct | Total # Correct | Fires # Correct | Nuisance # Correct | fires faster than ion | fires slower than ion | fires similar to photo | fires faster than photo | fires slower than photo | fires similar to ion | nuisances faster than ion | nuisances slower than ion | nuisances faster than photo | nuisances slower than photo | total fires faster | total fires similar | total fires other | total nuisances faster | total nuisances similar | total nuisances slower | total nuisances other | |
|-----------|--------------------|-------------|-----------------|-----------------|-------------------|-----------------|-----------------|--------------------|-----------------------|-----------------------|------------------------|-------------------------|-------------------------|----------------------|---------------------------|---------------------------|-----------------------------|-----------------------------|--------------------|---------------------|-------------------|------------------------|-------------------------|------------------------|-----------------------|----|
| 25 | 11% | 7 8 6 | 76.2 | 74.5 | 79.3 | 64 | 41 | 23 | 13 | 29 | 13 | 17 | 17 | 13 | 14 | 2 | 4 | 2 | 2 | 27 | 26 | 1 | 25 | 3 | | |
| 10 | 11% | 27 6 | 66.7 | 60.0 | 79.3 | 56 | 33 | 23 | 9 | 33 | 13 | 20 | 15 | 20 | 11 | 6 | 2 | 6 | 17 | 6 | 6 | 22 | 27 | 4 | 19 | 6 |
| 25 | 11% | 7 8 11 | 75.0 | 74.5 | 75.9 | 63 | 41 | 22 | 12 | 29 | 14 | 16 | 19 | 20 | 12 | 15 | 2 | 5 | 20 | 4 | 2 | 25 | 28 | 2 | 22 | 5 |
| 25 | 11% | 7 8 11 6 | 75.0 | 74.5 | 75.9 | 63 | 41 | 22 | 12 | 29 | 14 | 18 | 18 | 19 | 12 | 15 | 2 | 5 | 20 | 4 | 2 | 25 | 28 | 2 | 22 | 5 |
| 25 | 11% | 27 6 | 67.9 | 63.6 | 75.9 | 57 | 35 | 22 | 11 | 31 | 13 | 20 | 14 | 21 | 11 | 5 | 3 | 6 | 16 | 7 | 7 | 21 | 27 | 4 | 18 | 7 |
| 10 | 0.82% | 27 6 | 63.1 | 56.4 | 75.9 | 53 | 31 | 22 | 6 | 37 | 12 | 19 | 16 | 20 | 9 | 17 | 3 | 6 | 16 | 7 | 4 | 24 | 27 | 3 | 19 | 7 |
| 25 | 11% | 7 9 6 | 65.5 | 61.8 | 72.4 | 55 | 34 | 21 | 9 | 38 | 8 | 22 | 15 | 18 | 12 | 13 | 4 | 5 | 18 | 6 | 6 | 26 | 23 | 3 | 19 | 7 |
| 25 | 0.82% | 27 6 | 63.1 | 58.2 | 72.4 | 53 | 32 | 21 | 7 | 37 | 11 | 18 | 16 | 21 | 8 | 18 | 3 | 6 | 15 | 8 | 4 | 24 | 27 | 3 | 18 | 8 |
| 10 | 11% | 7 8 6 | 75.0 | 78.2 | 69.0 | 63 | 43 | 20 | 15 | 27 | 13 | 20 | 20 | 15 | 12 | 13 | 4 | 3 | 22 | 4 | 4 | 27 | 24 | 1 | 23 | 5 |
| 10 | 11% | 2 4 6 | 72.6 | 74.5 | 69.0 | 61 | 41 | 20 | 18 | 30 | 7 | 29 | 12 | 14 | 10 | 13 | 6 | 4 | 18 | 7 | 14 | 23 | 18 | 3 | 18 | 8 |
| 25 | 11% | 2 3 4 5 6 | 64.3 | 72.7 | 48.3 | 54 | 40 | 14 | 20 | 25 | 10 | 24 | 19 | 12 | 10 | 8 | 11 | 3 | 13 | 13 | 13 | 22 | 20 | 2 | 13 | 14 |
| 25 | 11% | 7 8 9 10 11 | 69.0 | 74.5 | 58.6 | 58 | 41 | 17 | 17 | 30 | 8 | 22 | 16 | 17 | 12 | 10 | 7 | 4 | 16 | 9 | 7 | 28 | 20 | 2 | 17 | 10 |

Table 12. Misclassified Fire/Nuisance Sources using Background Subtraction

| EWFD Test # | Description | EWFD Test # | Description |
|--------------------|---------------------------------|---------------------|------------------------------------|
| 25/25 11% 7 8 6 | | 10/25 1.63% 7 8 9 6 | |
| 011, 051, 071 | Smoldering Electrical | 011, 071, 085, | Smoldering Electrical |
| 085, 086, 088 | Cable | 086 | Cable |
| 020, 057 | PWB | 020, 033, 057 | PWB |
| 042 | Smoldering Oily Rag in trashcan | 042 | Smoldering Oily Rag in trashcan |
| 053 | Smoldering Bedding | 029 | Smoldering Bedding |
| 021, 034, 059 | Brief Wire overheat | 059 | Brief Wire overheat |
| 073 | | | |
| 012 | Arc Welding | | |
| | | 009, 027, 047 | Burning Popcorn |
| 009, 047 | Burning Popcorn | 006, 087 | Cigarette Smoking |
| 049 | Steel Cutting | 018, 048, 049 | Steel Cutting |
| 072, 080 | Cooking oil | 075 | Steam generation w/ propane burner |
| | | 072, 080 | Cooking oil |

5. PNNCV Training of Both Test Series 1 and 2

Test Series 1 and 2 were also tested using cross validation (PNNCV) as described in earlier reports.^{3,4,5,7} All of the tests for both test series were reviewed and a training set and a prediction set were generated. In some cases, the responses for tests were weak and not consistent across several replications. The tests that had questionable responses were not included in the training set. Table 13 lists all 54 tests included in the training set. The prediction set shown in Table 14 includes the replicates from the test series (17 tests) and as well as the weak responses (13 tests) that were discarded from the training set. All the experiments in italics were not included in the training set due to weak responses.

Table 13. Summary of Scenarios in training Set.

| EWFD Tests | Fire Scenario Description |
|-------------------|--|
| 001,008,038,043 | Heptane Pool Fire |
| 002,039 | Pipe Insulation Exposed to Fuel Oil Fire |
| 003,040 | Flaming Oily Rag and Paper in Small Trash Can |
| 022, 083 | Smoldering Oily Rag and Paper in Small Trash Can |
| 005,045 | Smoldering Plastic Bag of Mixed Trash |
| 007,046 | Plastic Trash Bag Fire next to TODCO Wallboard |
| 010,050 | Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire |
| 088 | Smoldering Electrical Cables (LSDSGU-14) |
| 019, 084 | Smoldering Bedding Material |
| 013,054 | Flaming Bedding Material |
| 056, 058 | Printed Wire Board Fire |
| 021,073 | Brief Overheat of a Wire |
| 060,061 | BSI 6266 Wire Overheat |
| 074,077 | Smoldering Electrical Cables (LSTPNW-1½ , MIL C-24643/52-01UN) |
| 016 | Wood Crib |
| 017 | Trashcan/office Chair |
| 031 | F02a: Pipe Insulation Exposed to Heptane Fire |
| 004,030 | Burning Toast |
| EWFD Tests | Nuisance Scenario Description |
| 041,065 | Toasting Pop Tarts™ |
| 012,052 | Welding Steel |
| 018,048 | Cutting Steel with acetylene torch |
| 009,047 | Burning popcorn |
| 006,068 | Cigarette smoke |
| 015,066 | Normal Toasting |
| 028,069 | Grinding Steel |
| 063 | Aerosol Deodorants |
| 064 | Sweeping up a dropped bag of flour |
| 076 | Steam generation. |
| 062,072 | Cooking oil |
| 024 | Nylon Rope |

Table 14. Summary of Scenarios in Prediction Set.

| EWFD Tests | Fire Scenario Description |
|-------------------|--|
| 044 | Heptane Pool Fire |
| 023 | Pipe Insulation Exposed to Fuel Oil Fire |
| 014,070 | Flaming Oily Rag and Paper in Small Trash Can |
| 035, 042 | Smoldering Oily Rag and Paper in Small Trash Can |
| 026 | Smoldering Plastic Bag of Mixed Trash |
| | Plastic Trash Bag Fire next to TODCO Wallboard |
| | Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire |
| 011,051,085,086 | Smoldering Electrical Cables (LSDSGU-14) |
| 029, 053 | Smoldering Bedding Material |
| | Flaming Bedding Material |
| 020,033,055, 057 | Printed Wire Board Fire |
| 034, 059 | Brief Overheat of a Wire |
| | BSI 6266 Wire Overheat |
| 071 | Smoldering Electrical Cables (LSTPNW-1½, MIL C-24643/52-01UN) |
| | Wood Crib |
| | Trashcan/office Chair |
| | F02a: Pipe Insulation Exposed to Heptane Fire |
| | Burning Toast |
| 025 | Nylon Rope into trashcan |
| EWFD Tests | Nuisance Scenario Description |
| | Toasting Pop Tarts™ |
| | Welding Steel |
| 049 | Cutting Steel with acetylene torch |
| 027 | Burning popcorn |
| 032, 087 | Cigarette smoke |
| 067 | Normal Toasting |
| | Grinding Steel |
| | Aerosol Deodorants |
| | Sweeping up a dropped bag of flour |
| 081,082, 075 | Steam generation. |
| 080 | Cooking oil |
| | Nylon Rope |

The training set was generated similar to the previous training sets with only slight changes being required. The raw sensor data was used for all sensors except the photo, which was converted to % obs/m. The ion detector was left as Δ MIC since an accurate conversion was not available at the time. The patterns were generated at the alarm times from the COTS detectors used in the field tests. The time used was from the first alarming detector, ion or photo, or 300 sec after ignition if neither detector alarmed. The patterns in the training set used a 10-point magnitude and 25-point slope averaging. The studies were conducted with and without backgrounds in the training and prediction sets. Background patterns were also generated for each experiment at the time just before ignition. For the training set with backgrounds, there is one background for each member of the training set; resulting in 108 patterns. Using PNNCV, Prototype 1 misclassified 18 fire/nuisance sources with and without backgrounds in the training set. The results are shown in Table 15. Prototype 2 misclassified 19 when no backgrounds were present, and only misclassified 13 using backgrounds as shown in Tables 16 and 17.

Table 15. Summary of Prototype 1 Misclassified Events Using PNNCV

| EWFD Tests | Fire Scenario Description |
|-------------------|--|
| 003,040 | Flaming Oily Rag and Paper in Small Trash Can |
| 022 | Smoldering Oily Rag and Paper in Small Trash Can |
| 046 | Plastic Trash Bag Fire next to TODCO Wallboard |
| 010,050 | Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire |
| 088 | Smoldering Electrical Cables (LSDSGU-14) |
| 019 | Smoldering Bedding Material |
| 054 | Flaming Bedding Material |
| 058 | Printed Wire Board Fire |
| 021, 073 | Brief Overheat of a Wire |
| 060,061 | BSI 6266 Wire Overheat |
| 004 | Burning Toast |
| EWFD Tests | Nuisance Scenario Description |
| 041 | Toasting Pop Tarts™ |
| 018 | Cutting Steel with acetylene torch |
| 072 | Cooking oil |

Table 16. Summary of Prototype 2 Misclassified Events Using PNNCV with no Backgrounds.

| EWFD Tests | Fire Scenario Description |
|-----------------|--|
| 001,008,038,043 | Heptane Pool Fire |
| 039 | Pipe Insulation Exposed to Fuel Oil Fire |
| 003,040 | Flaming Oily Rag and Paper in Small Trash Can |
| 022 | Smoldering Oily Rag and Paper in Small Trash Can |
| 005,045 | Smoldering Plastic Bag of Mixed Trash |
| 046 | Plastic Trash Bag Fire next to TODCO Wallboard |
| 050 | Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire |
| 088 | Smoldering Electrical Cables (LSDSGU-14) |
| 019 | Smoldering Bedding Material |
| 058 | Printed Wire Board Fire |
| 021,073 | Brief Overheat of a Wire |
| EWFD Tests | Nuisance Scenario Description |
| 018 | Cutting Steel with acetylene torch |
| 028 | Grinding Steel |

Table 17. Summary of Prototype 2 Misclassified Events Using PNNCV with Backgrounds

| EWFD Tests | Fire Scenario Description |
|------------|--|
| 022 | Smoldering Oily Rag and Paper in Small Trash Can |
| 010,050 | Electrical Cables and Pipe Insulation exposed to Laundry Pile Fire |
| 088 | Smoldering Electrical Cables (LSDSGU-14) |
| 084 | Smoldering Bedding Material |
| 054 | Flaming Bedding Material |
| 056,058 | Printed Wire Board Fire |
| 021,073 | Brief Overheat of a Wire |
| 077 | Smoldering Electrical Cables (LSTPNW-1½, MIL C-24643/52-01UN) |
| EWFD Tests | Nuisance Scenario Description |
| 012 | Welding Steel |
| | Background |

Varselpr, a feature selection routine, was used to determine the best set of sensors to correctly classify the training set. Several different sets of sensors were available for selection, (a) all, (b) all except prototype 1, (c) all except prototype 2, (d) prototype 1, and (e) prototype 2. Using the subsets of sensors determined by this method, the best PNNCV results were achieved with the hydrogen sulfide and hydrocarbon sensor in the set. However, subsets of prototypes 1 and 2 were also very strong as shown in Table 18. The results for the slope of CO (rCO), Photo, and the slope of ION (rION) are given in Table 19.

Using the 54 and 108 training sets, the prediction set was investigated with different combinations of sensors using the same methods as in Section 4, PNN optimization (playback mode). The results are shown in Table 20. The results in this Table are for the prediction set, a combination of the 17 replicates and the 13 discarded tests. The COTS and the prototype sensors generally perform poorly on the discarded tests, therefore all the results are low. The overall classification results are better than the COTS ion and similar to the COTS photo. The 108 training set was usually much faster than the COTS for predicting fires. More Nuisance sources are correctly classified with no backgrounds in the training set.

Table 21 divides the prediction set into two parts, so that the results for the weak tests (discarded tests) are easier to see. This table also consolidates the prediction set results with the training set results to give an overall classification to Test Series 1 and 2 that can be compared to Table 7, 8 10, and 11. The overall correct results are better than the COTS ion (56%), but weaker than the COTS photo (77%). Using Test Series 1 and 2 for the training data, the largest correct classifications of nuisance sources was achieved, but this PNN does not detect several of the fires. Prototype 1, using training set 54, did the best predicting the replicates and gave the best nuisance source recognition. Prototype 2 was best when backgrounds are present and was able to detect several of the discarded fires. The sensor subset ION, photo, and CO (sensors: 7 8 9) was also very strong. However, this method does not provide a significant improvement over the methods described in Section 4.

Table 18. Feature Selection Results

| Sensor Sets with No Backgrounds | Sensors (r means slope of sensor) | # missed |
|--|--|-----------------|
| A | H2S HC rO2 CO(4) CO(9) | 9 |
| B | H2S HC rO2 CO | 10 |
| C | H2S HC rO2 CO | 9 |
| D | CO rCO | 17 |
| E | rCO rION Photo | 16 |
| | | |
| Sensor Sets with Backgrounds | | |
| A | rCO CO rRION-C Photo rRION ION(2) | 11 |
| B | rCO rRION-C Photo HC rION H2S rH2S rION CO | 11 |
| C | CO rRION-C rHC rCO2 rRION NO | 12 |
| D | CO rCO rPhoto photo rCO2 CO2 | 17 |
| E | rCO Photo rION | 12 |

Table 19. Summary of rCO Photo rION Misclassified Events Using PNNCV

| EWFD Tests | Fire Scenario Description |
|-------------------|--|
| 002 | Pipe Insulation Exposed to Fuel Oil Fire |
| 040 | Flaming Oily Rag and Paper in Small Trash Can |
| 022 | Smoldering Oily Rag and Paper in Small Trash Can |
| 046 | Plastic Trash Bag Fire next to TODCO Wallboard |
| 088 | Smoldering Electrical Cables (LSDSGU-14) |
| 084 | Smoldering Bedding Material |
| 054 | Flaming Bedding Material |
| 073 | Brief Overheat of a Wire |
| 077 | Smoldering Electrical Cables (LSTPNW-1½ , MIL C-24643/52-01UN) |
| EWFD Tests | Nuisance Scenario Description |
| 052 | Welding Steel |
| 047 | Burning popcorn |
| 006 | Cigarette smoke |

Table 20. PNN classification comparison of training sets for Several Sensor Combinations using Test Series 1 and 2 Data

| DataSet | Prototype | Total % | | Fires % | | Nuisance % | | Total # | | Fires # | | Nuisance # | | fires faster than ion | fires similar to ion | fires slower than photo | fires similar to photo | fires faster than photo | fires slower than ion | nuisances faster than ion | nuisances similar to ion | nuisances slower than photo | nuisances faster than photo | nuisances similar to photo | total fires faster | total fires similar | total nuisances slower | total nuisances similar | total nuisances other |
|---------|--------------|---------|---------|---------|---------|------------|---------|---------|---------|---------|---------|------------|---------|-----------------------|----------------------|-------------------------|------------------------|-------------------------|-----------------------|---------------------------|--------------------------|-----------------------------|-----------------------------|----------------------------|--------------------|---------------------|------------------------|-------------------------|-----------------------|
| | | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | Correct | | | | | | | | | | | | | | | | |
| 54 | 1A | 66.7 | 52.4 | 100.0 | 20 | 11 | 9 | 4 | 14 | 3 | 7 | 8 | 6 | 4 | 5 | 0 | 3 | 9 | 0 | 2 | 11 | 8 | 1 | 8 | 0 | | | | |
| 108 | 1A | 60.0 | 66.7 | 44.4 | 18 | 14 | 4 | 7 | 12 | 2 | 11 | 6 | 4 | 1 | 4 | 4 | 2 | 2 | 5 | 6 | 9 | 6 | 0 | 4 | 5 | | | | |
| 54 | 2A | 46.7 | 42.9 | 55.6 | 14 | 9 | 5 | 4 | 15 | 2 | 5 | 8 | 8 | 4 | 2 | 3 | 2 | 3 | 4 | 2 | 10 | 9 | 1 | 4 | 4 | | | | |
| 108 | 2A | 60.0 | 71.4 | 33.3 | 18 | 15 | 3 | 8 | 13 | 0 | 9 | 7 | 5 | 3 | 3 | 3 | 2 | 3 | 4 | 4 | 12 | 5 | 1 | 3 | 5 | | | | |
| 54 | 2 3 4 | 63.3 | 57.1 | 77.8 | 19 | 12 | 7 | 6 | 13 | 2 | 7 | 9 | 5 | 3 | 5 | 1 | 3 | 4 | 2 | 3 | 11 | 7 | 1 | 6 | 2 | | | | |
| 108 | 2 3 4 | 66.7 | 81.0 | 33.3 | 20 | 17 | 3 | 10 | 10 | 1 | 13 | 5 | 3 | 2 | 4 | 3 | 2 | 3 | 4 | 8 | 9 | 4 | 0 | 3 | 6 | | | | |
| 54 | 7 8 9 | 56.7 | 47.6 | 77.8 | 17 | 10 | 7 | 3 | 16 | 2 | 6 | 8 | 7 | 3 | 6 | 0 | 2 | 6 | 1 | 1 | 12 | 8 | 0 | 8 | 1 | | | | |
| 108 | 7 8 9 | 63.3 | 66.7 | 55.6 | 19 | 14 | 5 | 7 | 14 | 0 | 9 | 7 | 5 | 2 | 5 | 2 | 1 | 4 | 4 | 4 | 12 | 5 | 0 | 5 | 4 | | | | |
| 108 | 4 8 27 | 70.0 | 76.2 | 55.6 | 21 | 16 | 5 | 9 | 11 | 1 | 9 | 7 | 5 | 3 | 4 | 2 | 1 | 5 | 3 | 4 | 11 | 6 | 0 | 6 | 3 | | | | |
| 108 | 4 8 23 25 27 | 56.7 | 66.7 | 33.3 | 17 | 14 | 3 | 6 | 14 | 1 | 9 | 9 | 3 | 3 | 2 | 4 | 1 | 4 | 4 | 4 | 13 | 4 | 0 | 4 | 5 | | | | |
| 108 | 4 6 24 25 27 | 60.0 | 71.4 | 33.3 | 18 | 15 | 3 | 8 | 12 | 1 | 12 | 7 | 2 | 1 | 3 | 5 | 1 | 3 | 5 | 7 | 11 | 3 | 0 | 3 | 6 | | | | |
| COTS | Ion | 43.3 | 38.1 | 55.6 | 13 | 8 | 5 | | | | | | | | | | | | | | | | | | | | | | |
| | Photo | 63.3 | 61.9 | 66.7 | 19 | 13 | 6 | | | | | | | | | | | | | | | | | | | | | | |
| | Ion+Photo | | 71.4 | 33.3 | | | | | | | | | | | | | | | | | | | | | | | | | |

Table 21. Results Using Test Series 1 and 2 For Training and Prediction

| Training Set | Sensors | Prediction Set | | | | Overall Correct for Test Series 1 and 2 #Correct* | | |
|--------------|--------------|---------------------------|-----------|--------------------------|-----------|---|-----------|------|
| | | Replicate Tests # Correct | | Discarded Tests #Correct | | | | |
| | | Fires (9) | Nuis. (8) | Fires (12) | Nuis. (1) | Fires (55) | Nuis (29) | % |
| 54 | 1A | 9 | 8 | 2 | 1 | 30 | 26 | 66.7 |
| 108 | 1A | 9 | 4 | 5 | 0 | 33 | 21 | 60.7 |
| 54 | 2A | 7 | 5 | 2 | 0 | 26 | 23 | 58.3 |
| 108 | 2A | 9 | 3 | 6 | 0 | 38 | 22 | 71.4 |
| 54 | 2 3 4 | 8 | 6 | 4 | 1 | 32 | 22 | 64.3 |
| 108 | 2 3 4 | 9 | 3 | 8 | 0 | 37 | 18 | 65.5 |
| 54 | 7 8 9 | 8 | 6 | 2 | 1 | 35 | 24 | 70.2 |
| 108 | 7 8 9 | 9 | 4 | 5 | 1 | 37 | 21 | 69.0 |
| 108 | 4 8 27 | 9 | 4 | 7 | 1 | | | |
| 108 | 4 8 23 25 27 | 9 | 2 | 5 | 1 | | | |
| 108 | 4 6 24 25 27 | 9 | 2 | 6 | 1 | | | |

*Results combine the prediction results with the PNNCV results for the training set

6. Conclusions

This test series demonstrated an early warning fire detection system consisting of a sensor array and a PNN operated in real-time on the ex-USS SHADWELL. The EWFD provides very good results with faster fire detection than COTS ion and photo detectors. Significant improvements have been demonstrated by optimizing the training set and the ion sensor calibration. For Test Series 1 and 2, a subset of sensors rather than the full set used in prototypes 1 and 2 gave the best results. In addition, background subtraction improved the overall classification as well as the detection speed.

Based on the results described in this report, the ION, Photo, CO, and CO₂ (sensors: 7 8 9 6) sensors are recommended for real-time analysis during Test Series 3 using 10-point magnitude and 25-point slope determinations, background subtraction and trained at 1.63% obs/m photoelectric detector alarm times. Several other sensor combinations will also be evaluated after each test. If it is determined that any of the alternative methods are better than the real-time analysis methods, the real-time analysis method will be changed. The best method will be tested before Test Series 3 is complete.

The following combinations will be tested during Test Series 3:

Real-time

| | | | |
|---------------------------------|-------|------------------------|-------------------|
| ION, Photo, CO, CO ₂ | 10/25 | background subtraction | 1.63% Alarm times |
|---------------------------------|-------|------------------------|-------------------|

Playback Mode(off line)

| | | | |
|--------------------------|-------|---------------------------|---------------------|
| ION, Photo, Temp | 25/25 | background subtraction | 11% Alarm times |
| ION, Photo, Temp | 25/25 | no background subtraction | 11% Alarm times |
| ION, Photo, CO | 25/25 | no background subtraction | Test Series 1 and 2 |
| Prototype 1 | 25/25 | no background subtraction | All data |
| Prototype 2 | 25/25 | no background subtraction | All data |
| ION, CO, CO ₂ | 10/25 | background subtraction | 11% Alarm times |

The probability cut off for alarm will also be investigated during Test Series 3. To date, a probability cut off of 0.75 has been used. It may be possible to improve nuisance source rejection and maintain fast fire detection if this level is increased to 0.85-0.90%. Tests will be conducted to determine if it is more appropriate to issue a warning at 0.75 and alarm at 0.85.

7. References

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Appendix A

Real-time PNN Matlab code

```
function [w,p,pattern,alarm_state,data_history,alarm_history] =
rtpnncode_lab4(Xcurrent,bckgrd,data_history,alarm_history,train,tinfo,s
igma,alarmprob)
% RTPnncode_lab - Code written to be incorporated into Labview for use
during real-time fire testing on the ex-USS Shadwell
%
% Version 0.1 - 1/11/00 - Sean J. Hart
% Version 0.2 - 1/20/00 - SJH - Modified averaging, added alarm
probability and fire criterion for alarms
% Version 0.3 - 1/28/00 - SJH - Removed redundant variable data_average
from input and output lists
% Version 0.4 - 1/31/00 - SJH - Modified code to use preprocess type 3
(engineering units and no background subtraction with selection code 8
(mag/slope calc)
% Version 0.5 - 1/31/00 - SJH - Removed redundant variables buffer size
and average size as they are no longer needed
% Version 1.0 - 4/13/00 - SJH - Removed buffer_data as averaging was
slowing us down and allowing averaged zeros to be included in data
history
% Outputs-
% w:          class winner determined by PNN
% p:          PNN probability
% pattern:    processed sensor values used by the PNN
% alarm_state: current alarm condition
% data_history: a buffer of data points from which to calculate
baselines and slopes
% data_average: the averaged raw data points from buffer_data
% buffer_data:  a buffer of raw data points from which to calculate
an average raw input
% alarm_history: a record of alarm conditions
%
% Inputs-
% Xcurrent:    sensor input values
% bckgrd:      backgr supplied by HAI
% data_history: record of
% alarm_history: record of alarm states
% train:       Training set patterns
% tinfo:       Training set info
% sigma:       Training kernel width
% alarmprob:    Probability at which to alarm
%
%
```

```

[junk,numensors] = size(Xcurrent);

% ***** Some constants
*****

slopeflag = 1;
slopelength = 25;
maglength = 25;
x = (1:slopelength)';

if maglength > slopelength
    startcalc = maglength;
else
    startcalc = slopelength;
end

% ***** Background subtraction and conversion
calculations *****

converted_data = Xcurrent;

[y] = polyval([0.0000034 -0.0004140 0.0171968 -0.2070225
0.0004794],converted_data(1)); % convert delta mic to %obs/ft
converted_data(1) = (1-((1-(y/100)).^(3.28)))*100; % convert to
%/meter
converted_data(2) = (1-((1-(converted_data(2)/100)).^3.28))*100; %
convert %/ft to %/meter

% ***** Data History - average data for baseline
/ slope calc *****

data_history = [data_history;converted_data]; %add row to end of matrix
- Size of data_history limits the number of points that can be used for
the slope calc
data_history = delsamps(data_history,1); %remove oldest row in matrix

%***** MAG / slope calc
*****

for k = 1:numensors % each sensor (column)
    testpointsmag = data_history(:,k);
    pattern(:,k) = mean(testpointsmag);
    if slopeflag == 1
        testpointsslope = data_history(:,k);
        temp2 = polyfit(x,testpointsslope,1);
        pattern(:,k+numensors) = temp2(1);
    end
end

%Select combination of MAG and Slopes to match training set
%pattern = pattern([1 2 3 4 5 6 7 8]);

```

```

% ***** Call PNN and trigger alarm state
%*****

    rowstoaverage = find(mean(data_history,2)== 0); % makes sure that
    zeros are not included in the average at start of data collection

    if (isempty(rowstoaverage) == 1)

        %[atrain,mx] = mncn(train); %Mean center training set - can
        remove this set and pass it in each time if speed is required
        %[apattern] = scale(pattern,mx); % Scale prediction pattern
        according to training set scaling

        [atrain,mx,stdx] = auto(train); %Autoscale training set - can
        remove this set and pass it in each time if speed is required
        [apattern] = scale(pattern,mx,stdx); % Scale prediction pattern
        according to training set scaling
        [w,p] = pnnpred(atrain,tinfo,apattern,sigma,2); % Evaluate
        pattern using PNN

    else

        w = 0;
        p = zeros(1,2);

    end

% ***** Probability alarm
decision*****

if (p(1) > alarmprob) % If PNN probability is greater than cutoff then
set alarm_history
    alarm = 1; % alarm on
    alarm_history = [alarm_history;alarm];
else
    alarm = 0; % alarm on
    alarm_history = [alarm_history;alarm];
end

alarm_history = delsamps(alarm_history,1); %remove oldest row in matrix

% ***** Fire criterion alarm
decision*****

alarmzeros = find(alarm_history == 0); % Find out if the alarm has been
set in any of the last n alarms (size of alarm_history define the check
window)
if (isempty(alarmzeros) == 1) % Set the alarm state on if all elements
of alarm_history have been non-zero (i.e. Fire present)
    alarm_state = 1; %Alarm state on - signals a fire
else
    alarm_state = 0; %Alarm state off - signals no fire
end

```